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Study of Chemical Toxicity of Low-Level Wastes

Main Report

General Research Corporation

Prepared for
U.S. Nuclear Regulatory Commission

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Prepared for
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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ABSTRACT

The chemical composition of fuel-cycle wastes is reasonably well-known. By comparison, there is little information on the chemical composition of non-fuel cycle wastes. Such non-fuel cycle wastes come from a variety of sources--industrial, chemical, and medical. Because of the paucity of information, it is difficult to define the chemical characteristics and to evaluate potential hazards of non-fuel cycle wastes as a result of chemical toxicity.

This report provides an assessment of the chemical toxicity of low-level radioactive wastes based on literature reviews, preparation of bibliographies and monographs, and application of a variety of methodologies either being currently applied or being proposed for relative hazard assessments. The report relies primarily on data from the Maxey Flats, Kentucky, waste disposal site. While there are differences between humid and dry sites, the findings are believed to be generally applicable to evaluating the chemical toxicity of wastes at all low-level radioactive waste burial sites.

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PREFACE

This report is presented in two volumes and provides an assessment of the chemical toxicity of low-level radioactive wastes based on literature reviews, preparation of bibliographies and monographs, and application of a variety of methodologies either currently being applied or being proposed for relative hazard assessments.

Volume I contains eight chapters with appendices. Chapter 1 is the introduction; Chapter 2 describes the volume, physical form, and chemical characteristics of low-level radioactive wastes. Chapter 3 addresses the chemical toxicity of low-level wastes and discusses the toxicity of specific substances representative of non-fuel cycle and fuel cycle wastes; Chapter 4 discusses burial site characteristics and operations; Chapter 5 describes factors that influence the persistence and movement of materials in a shallow land burial facility; Chapter 6 provides various approaches to risk assessment and relative hazard assessment that might be useful in managing a burial site; Chapter 7 contains recommendations to mitigate potential adverse effects from any associated chemical toxicity of the radioactive wastes; and Chapter 8 lists the references cited in Volume I.

Volume II contains 18 monographs on substances that represent the classes of compounds identified in trench water samples at Maxey Flats. Descriptions of literature search techniques and factors considered in evaluating the literature are included.

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1.0 INTRODUCTION

1.1 NRC Low-Level Waste Management Program

The United States Nuclear Regulatory Commission (NRC) is charged with the responsibility of assuring that the civilian uses and operation of facilities involving the use or disposal of nuclear materials are conducted in a manner consistant with public health and safety, maintenance of environmental quality, national security, and antitrust laws. While a substantial share of the Commission's efforts is concerned with the use of nuclear fuels to generate electrical power, there are significant responsibilities involving medical, industrial, and research uses of radioactive materials. The NRC's Office of Nuclear Material Safety and Safeguards has the major responsibility to provide for the safe use of radioactive materials from the point of generation to disposal and monitoring the performance of disposal sites.

NRC responsibilities are fulfilled through a system of licensing and regulation which covers, among other activities, the possession, use, processing, transport, handling, and disposal of nuclear materials. The NRC also is responsible for the development and implementation of rules and regulations; conduct of public hearings on matters related to nuclear safety; and development of effective working relationships with the states regarding the regulation of nuclear materials. In an agreement with the states, the procedures for disposal of waste at the Beatty, Hanford and Barnwell facilities are licensed by state organizations. These state programs are consistent with the licensing objectives of the NRC.

Shallow land burial is the current method for the disposal and containment of low-level radioactive wastes. Presently, there are six low-level disposal sites in the United States. The locations are: Maxey Flats (Morehead), Kentucky; Beatty, Nevada; Sheffield, Illinois; Barnwell, South Carolina; West Valley, New York; and Richland, Washington. Currently only the Beatty, Barnwell, and Richland sites are operational.

Waste materials at these sites contain a wide variety of toxic chemicals associated with the radioactive wastes. The adequacy of shallow land burial facilities to contain wastes in which the chemical hazard exceeds that of the radiological hazard has not been evaluated quantitatively. This is, in part, due to a lack of information on the

chemical characteristics of the wastes and their potential toxic effects and, in part, due to a lack of an adequate quantitative method for comparing radiological hazards with chemical hazards.

Operation of shallow land burial facilities is subject to a system of licensing and regulation that has been established by the NRC. Low-level radioactive waste generated from both fuel cycle and non-fuel cycle sources comprise the major constituents in these shallow land burial facilities.

1.2 Issues Regarding Shallow Land Burial Sites

The licensing and regulation of shallow land burial facilities involve a number of issues related to the chemical characteristics of the wastes and the assessment of chemical toxicity and radiological toxicity. These issues include:

- The effects of chemicals in the waste on the design parameters of the facility.

- The identification and elimination of chemicals in the waste that will enhance migration of toxic materials or degrade performance of the facility.

- The concentrations of such chemicals necessary to damage facility performance.

- Identification of exposure concentrations and conditions potentially hazardous to reclaimers.

- The influence of solidification agents, (urea-formaldehyde, DOW polymer, asphalt, or cement) on performance of the facilities.

- The health and safety of personnel potentially exposed to toxic chemicals.

- The influence of on-site treatment systems such as incineration, concentration, or solidification of wastes on enhancement or mitigation of chemical hazards.

- Possible disposal of low-level radioactive wastes at alternative sites for chemicals found to exceed the radioactive hazard.

- Advantages and disadvantages of segregating fuel cycle wastes from non-fuel cycle wastes.

- Chemical Monitoring of Sites

These issues are particularly significant in addressing the concerns of the states in managing the chemical toxicity associated with shallow land burial of low-level radioactive wastes.

In the spring of 1979, South Carolina halted shipments of organic liquid wastes to its burial ground at Barnwell on the grounds that the material--as distinct from the radioactive material itself--was a threat to the environment. The Washington Post quoted Phillip Lorio, Chief Radiation Safety Officer at Columbia University as saying, "The chemicals used as the carriers for radioactive tracers are toluene and xylene; South Carolina banned the burial of these two chemicals, which in effect was a ban on all of our radioactive waste...."

The governors of Nevada and Washington have closed, and subsequently reopened, both the Hanford and Beatty sites because of the transportation violations. South Carolina responded to these closings by stating that it would not receive wastes which would have gone to those sites.

The governors of South Carolina, Nevada and Washington presented the NRC, the Department of Transportation (DOT), and the Department of Energy (DOE) with letters requesting a detailed plan to upgrade inspection and enforcement of the rules for proper packaging and shipment of commercially-generated low-level nuclear wastes (Neel, 1979). The details of the new program were issued on September 1, 1979. In addition, the NRC has amended its regulations to allow NRC inspectors to enforce DOT regulations for shipping radioactive materials.

These and other related issues require an improved understanding of the chemical toxicity of low-level radioactive wastes and development of effective methodologies to manage and evaluate chemical and radiologic hazards in these waste materials.

1.3 Study Objectives and Approaches

The major objectives of this study were to characterize the chemical toxicity associated with low-level radioactive wastes and to develop recommendations for the prevention or mitigation of potentially adverse effects of hazardous chemicals in shallow land burial facilities. This was completed through a series of tasks that included: a review of records to determine the volume, physical form, and chemical properties of wastes at the burial sites; surveys to evaluate the characteristics of the facilities; a review of the literature on representative chemicals to characterize chemical hazards; assessment of the current status of knowledge on geohydrological factors affecting performance of a site; and identification of approaches for making relative hazard assessments for comparing radioactive hazards with toxic chemical hazards.

1.4 Summary of Results

The results of this study include an inventory and characterization of wastes at shallow land burial facilities, assessment of chemical toxicity of representative compounds, assessment of burial site characteristics, identification of factors influencing the persistence and movement of materials, approaches to relative hazards assessment, and recommendations for improved operations and management of chemical toxicity hazards at the facilities.

1.4.1 Characteristics of Wastes

Utilizing selective interview surveys and an extensive literature search, information was obtained on radioactive wastes currently in or being delivered to shallow land burial sites. Approximately 80 percent of the waste can be generally characterized as to its chemical composition. A degree of uncertainty as to the chemical identity arises from the lack of waste descriptions by the waste generator, as well as the disposal of non-radioactive materials via the radioactive waste route.

Non-fuel-cycle waste generators (e.g., academic institutions, hospitals, medical laboratories, radiochemical manufacturers, research laboratories, and other industries) produce

approximately 49 percent of the total waste consigned for shallow land burial. The academic and medical community contributes an estimated 25 percent of the total volume, about half of which is in the form of scintillation vials filled with toluene, or other liquids absorbed on solids or otherwise solidified (NUS Corp., 1979). The solids generated are similar to those of fuel cycle trash waste, but contaminated with radioisotopes used for research. The physical form of the waste, and its packaging, are of importance because these factors will influence the rate at which the waste may be transformed and/or transported in the environment.

Approximately 43 percent of the waste volume present in shallow land burial sites is comprised of fuel cycle wastes originating in the conversion, fuel fabrication, and reactor operations. These wastes are in the form of uranium-contaminated calcium fluoride, filters, spent ion exchange resins, filter sludges, contaminated clothing, evaporator concentrates and equipment (see Section 2.3 for a complete characterization). They are packaged in steel drums or cylinders, concrete boxes or cardboard boxes. The remaining 6 percent is from government and military waste generators.

1.4.2 Chemical Toxicity

Development of information to express the hazards of chemical toxicity and radiologic toxicity in commensurate and quantitative terms would provide a basis for the comparison of various waste disposal and risk management options. The data requirements for ranking the chemical and radiologic hazards fall into five categories. They are: substance identification; exposure; epidemiology (populations-at-risk); biological effects; and environmental effects.

A summary of the types of compounds likely to be found in low-level waste burial sites is presented in Section 3.0. In evaluating the potential adverse effects from toxic chemical wastes, the substances analyzed by Columbo, Weiss, and Francis (1977) in the trench waters of Maxey Flats, Kentucky are discussed.

The estimated Maxey Flats concentrations for some of the compounds do not represent a significant toxicological risk, and no acute or chronic adverse effects would be expected at the indicated concentrations. There is insufficient information to estimate any risks associated with suspected carcinogenic, mutagenic or teratogenic compounds. The potential human health and environmental hazards of selected organic, inorganic and elemental species are summarized in Sections 3.4.2, 3.5.1, 3.5.2, and 3.5.3, respectively.

1.4.3 Characteristics of Burial Sites

The design and construction of waste disposal facilities at all sites are similar. Open trenches are used as the primary burial facility with the excavated material being used as intermediate and final cover. Techniques to cover and seal the waste vary by site and relate more to local climate conditions than to differences in company procedures.

The states, which license disposal sites and the federal government, have the responsibility for defining the safety provisions for site operations, inspections during operation, decommissioning and long-term surveillance. The sequence of events of site operations from receipt of material to trench closure with associated regulations and precautions is covered in Section 4.3.

The single most important factor affecting the containment capability of a burial ground is the degree to which ground and surface waters can contact the waste and subsequently cause migration of any residual toxic chemicals. The factors which govern waste movement are peculiar to each site and must be evaluated specifically when relating the chemical hazard to the probability of release. Existing environmental monitoring programs are directed towards detecting radioisotope movement and providing a continuing record of site conditions.

Because of the decay properties of radioactive material at some future time the hazard of the radioactivity may be judged to be sufficiently low as to release some of the long-term controls. This time period has not been defined, but has been postulated as a few hundred years (DOE, 1978). Future constraints on use of the site are being evaluated in terms of exposure to the public of radiation exceeding appropriate limits as may be defined by federal regulatory agencies. Unrestricted use would mean that no constraints are placed on the use of the property and all potential pathways for exposure to the public would have to be considered.

1.4.4 Persistence and Movement of Materials

The hazards posed by waste constituents depend to a large extent on the constituent's mobility and potential for escape. Several alternative removal/degradation processes exist and include volatilization, precipitation or filtration processes, and aqueous transport, the latter being the most significant of the potential pathways. Satisfactory waste management strategy depends on subtantial control over these site-specific processes. The key concerns are the mobility and lifetime of the compounds.

Chemical compounds divide naturally into two groups, inorganics and organics. Inorganics are most susceptible to the processes of ion exchange, precipitation and adsorption. Organics generally are subject to chemical and biological degradation processes. Discussions relevant to selected inorganic and organic compounds are given in Sections 5.2.1.4 and 5.2.2.4, respectively.

Evaluation of waste mobility and degradation processes allows the establishment of a framework for ranking the relative hazards posed by representative constituents. Inorganics may be ranked in terms of mobility, and by this approach, the three elements of greatest concern appear to be cadmium, copper and chromium. Organic compounds cannot be ranked accordingly because the analysis depends on judgment rather than well defined data. However, statements can be made on the tendency of an organic compound to migrate and to persist. No extremes (i.e., highly mobile,

long-lived compounds) were determined, but compounds that may approach these extremes are 1,1,1-trichloroethane, 1,4-dioxane, and toluene.

It is cautioned that the data base for the transport and fate of waste constituents is too limited for a comprehensive assessment. Substantial research is necessary before solid data will underlie good estimates of transport and fate.

1.4.5 Relative Hazards Assessment

A variety of methods have been proposed in the literature to assess radiotoxicity or relative hazards for radionuclides. Virtually all of the methods make use of MPC (maximum permissible concentration) values as a starting point. Refinements include consideration of such factors as the probability of taking a certain quantity of the nuclide into the body, the transport of nuclides through the environment (including foodstuffs), and the probability of removing concentrations of nuclides from some location (such as a burial site). It is clear that the reliability of any such index of relative hazard will depend on the limitations associated with the MPC values and on a knowledge of the movement and transport of nuclides (or chemical compounds containing nuclides) from the environment to man.

As an initial approach, the use of the MPC as currently specified is probably adequate as a measure of radiotoxicity. This should be appropriately coupled with a suitable chemical toxicity index to provide an overall radio-chemical toxicity rating. Refinements dealing with the movement of various radioactive chemical forms from the waste site to the environment and to man could be added in assigning an overall hazard index for a particular compound.

Chemical hazard assessment is based on evaluation of exposure and adverse effects data. Such data may be incomplete and show varying degrees of uncertainty. Also, there is generally a lack of definition for dose-response relationships at low levels of potential exposure, and hazard assessments are often based on averaged data and

broadly based assumptions concerning the dose response. A variety of approaches may be applicable to assessing hazards of chemicals in shallow land burial sites. The hazard assessment methodology applied needs to be based on defined procedures. While ranking of chemical hazards at a site depends partially on site-specific characteristics, it also depends on the evaluation of typical site exposures and any potential adverse effects of such exposures.

1.4.6 Recommendations

The following recommendations address the issues cited in Section 1.2 and are concerned with the toxicologic and radiologic characteristics of waste and the licensing and regulation of shallow land burial facilities.

The effects of waste constituents on the design parameters of a facility are minimal based on the current volumes and chemical distribution of the wastes. Barriers which prevent off-site transport of any water soluble material contaminated with radioactivity, must be evaluated according to individual site conditions and integrated into facility design and operation. Natural barriers would include container integrity, collection and treatment of contaminated water, and the use of water resistant barriers such as plastic covers, soil cover, and paving materials. Modifications in burial ground practices which would further decrease the likelihood of off-site transport include: segregation of fuel cycle and non-fuel cycle wastes; maintenance of packaging integrity; improved management of water flows through trench capping, treatment of leachates, and monitoring of aquifers.

Chemicals such as chelating agents, surfactants, and strong acids or bases, should be regulated to avoid development of significant concentrations in trench waters and to prevent mobilization of radionuclides and toxic chemicals. It is also recommended that non-radioactive chemicals be excluded from the low-level disposal sites through the use of licenses and permits. On-site treatment systems may enhance or mitigate chemical hazards. Asphalt immobilization can eliminate

hazards from metallic salts. Incineration removes problems associated with toxic organic materials but may enhance the difficulties of airborne transport and occupational exposure.

Chemical monitoring of sites involves systematic analysis of trench waters, and air sampling. Trench water analysis should be an annual evaluation of acid soluble, base soluble, and neutral soluble materials, and of substances that are extractable by hexane, ether, and aromatic solvents. Air monitoring on site is concerned with the evaluation of personnel exposure.

Potential hazards presented to the reclaimer depend largely on the chemical's characteristics and mode of action. These effects may be mitigated through improved enforcement of waste toxicity certifications, segregation of fuel cycle and non-fuel cycle wastes, better packaging of toxic materials, and improvement in control over personnel exposure and material handling procedures. The influence of solidification agents on potential hazards to the reclaimer is dependent on their degree of chemical degradation and persistence. More information is needed on the long term reactions of these materials in the soil to provide an assessment of any potential hazards.

The health and safety of facility personnel can be properly maintained through accurate record keeping and accident reports, establishment of standards and performance criteria, proper designation of hazardous areas, routine medical surveillance, training of employees, and adequate protective devices.

If the above recommendations related to the packaging, identification, and monitoring of toxic materials are implemented, then it may not be necessary to segregate fuel cycle and non-fuel cycle wastes at shallow land burial facilities. However, if current practices of packaging, identification and control of institutional materials are continued, then a requirement for segregation is justified. Substances with a chemical hazard less than or equal to the radiologic hazard can be disposed of

adequately at a low level waste site. However, substances with a chemical hazard greater than the radiologic hazard should be disposed of at a site providing the additional protection necessary for the degree of hazard (e.g., restricting disposal to elevated geographical locations in arid or semi-arid environments).

2.0 CHEMICAL AND PHYSICAL FORM AND VOLUME CHARACTERIZATION OF WASTES DISPOSED IN SHALLOW LAND BURIAL SITES

2.1 Introduction

2.1.1 Objective

The objective of this section is to establish the chemical identity, volume, and physical form of material present in and associated with radioactive wastes currently in or being delivered to shallow land burial sites. The wastes to be considered to include both those originating from the various elements of the nuclear fuel cycle and those originating from non-fuel cycle activities. In the accomplishment of this task, the most recent and pertinent literature was reviewed, interviews with waste generators and waste disposal companies were conducted, and current shallow land burial site practices were investigated.

2.1.2 Definition of Radioactive Waste

The waste from nuclear power plants and supporting industries are considered the fuel cycle wastes, and the wastes from hospitals, universities, radioisotope manufacturers and others are considered the non-fuel cycle wastes.

Radioactive wastes are generally classified into the following three categories: (1) high level: those wastes generated from the reprocessing of spent reactor fuel*; (2) transuranium contaminated: contaminated with those elements with atomic number greater than 92; and (3) other-than-high-level wastes: the balance of generated radioactive wastes. This latter category is known as low level wastes (Holcomb, 1978) and is currently sent to

*10CFR50, Appendix F, however, defines high level wastes as "...those aqueous wastes resulting from the operation of the first cycle extraction system, or equivalent, and the concentrated wastes from subsequent cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels." Unreprocessed spent fuel is also considered to be high-level waste.

commercial shallow land burial facilities. Low level wastes are further categorized as follows:

Special Nuclear Material:	^{235}U in concentrations exceeding 0.71%, ^{233}U, Pu.
Source Material:	Any material containing natural uranium or thorium, or combinations thereof in concentrations exceeding 0.05%.
Byproduct Material:	All other radioisotopes produced by or made radioactive as a result of the fission process or any other nuclear process in the utilization of SNM.

2.1.3 Inventory of Wastes at Burial Sites

An update by the Environmental Protection Agency (EPA), of the inventory of low-level radioactive waste buried at commercial facilities through 1976 was reported in Nuclear Safety, (Holcomb, 1978).

As a part of the EPA inventory, the state representatives were asked to determine the percentages of fuel cycle and non-fuel cycle wastes. Table 2-1 summarizes the 1975 percentage data. The 39% figure for the non-fuel cycle waste generation agrees with a previous estimate of 44% for this time period (Holcomb, 1978). A recent study by the NUS Corporation cites institutional and non-nuclear industry percentages as 51%, nuclear power plants as 43%, and government as 6% of the total volume of waste (NUS, 1979).

Although these figures on volume are given with apparent precision, it must be remembered that they are based on compilation of shipping reports and are liable to considerable error. Figures based on inventory at the burial sites appear to have been first published by Clark (Clark, 1973), who studied

the Maxey Flats burial ground in Kentucky. Clark points out a number of irregularities in the records maintained by the operator, and notes that some non-radicactive chemical wastes appeared to have been accepted and buried. Clark also discusses the question of chemical toxicity, and recommends a more thorough study of this aspect of wastes being consigned to the burial grounds; he also recommends that shipping documentation include specific information on chemical composition and toxicity of materials consigned for burial.

TABLE 2-1

WASTE VOLUME PARTITIONING BY SOURCE

1975

Site	Percent Fuel-Cycle Waste*	Percent Nonfuel-Cycle Waste*
Kentucky+	50% (8,554)	50% (8,554)
Nevada	59% (2,916)	41% (2,026)
South Carolina	63% (11,232)	37% (6,597)
Illinois	76% (10,728)	24% (3,388)
New York++		
Washington	35% (525)	65% (975)
TOTAL	61% (33,955)	39% (21,540)

* Numbers in parentheses are waste volumes in cubic meters.

+ Estimated.

++ Information not available for 1975; site closed since March 1975.

2.2 Characterization of Non-Fuel Cycle Waste

2.2.1 Definition of Non-Fuel Cycle Waste

Non-fuel cycle waste is that waste generated by the use of radioactive materials in research, industry, education, and medicine. Currently, permissible disposal practices are: transfer to an authorized recipient (shallow land burial ground)(in accordance with 10CFR20.301), hold for decay, release to sewer (in accordance with 10CFR20.303), incineration (subject to specific approval by NRC)(in accordance with 10FR20.305), burial on site (in accordance with 10CFR20.304 and 10CFR20.302). This section examines only that portion which is disposed of in shallow land burial at licensed commercial burial grounds.

2.2.1.1 Literature Search

The literature search portion of this task regarding the non-fuel cycle waste generation revealed no specific information relating to the chemical nature of the waste produced. A study by the Radiation Safety Office, University of Maryland, encompasses a survey of 686 large medical and educational institutions regarding their waste volumes, methods of disposal, and primary isotope concentrations (Anderson, 1978). This study, now published by the Nuclear Regulatory Commission, will be referred to in this report as the Maryland Report. A follow up survey was reported in October, 1979 (Beck, 1979).

These reports proved to be a significant source of information for this study. Although the Maryland group was not concerned with the specific nature of wastes generated by the medical institutions surveyed, they did provide a general classification. More importantly, perhaps, the Maryland Report results provided both a basis for extrapolating some of our own data, and a yardstick for assessing some of our own information sources. We feel that some of our results in turn provide a valuable extension of that report.

2.2.1.2 Interview Survey

To obtain information on the character of waste generated, a selected list of waste generators was established for contact and interview. Selection for our interview list was accomplished by discussion with (1) major commercial waste disposers: Rad Services, Chem Nuclear, Hittman Nuclear, and a health physics service; (2) NRC and Agreement State personnel; and (3) staff consultations. Selection was made of local (Washington area) sources where possible; but specifically, selection was made to give a broad perspective of the non-fuel cycle waste generator population.

NRC provided a computer list of all current licensees, and from this list the type and license number of each interviewee was determined. Where the licenses were available they were reviewed prior to the interview.* The license application for "Byproduct Material License" (AEC-313 and 313 a) contains the following instructions for description of chemical and/or physical form:

6. (a) List by name each radioisotope desired such as "Carbon 14," "Cobalt 60," etc.

   (b) List chemical and/or physical form for _each_ radioisotope and the quantity of _each_ which the applicant desires to possess at any one time. If more than one chemical or physical form of a particular radioisotope is desired, a _separate_ possession limit should be stated for each form. For example, an applicant desiring to use two chemical forms of Iodine 131 must specify both forms and a possession limit for _each_ form. Example:

*It was not possible to obtain the dockets of several of the licensees, as they were stated to be in use by members of the NRC staff.

Iodine 131	Iodide	10 milli-curies
Iodine 131	Iodinated Human Serum Albumin	1 milli-curie
Krypton 85	Gas	1000 milli-curies

If the byproduct material is to be obtained as a sealed source(s), specify the manufacturer, model number, and amount of activity in each sealed source. Example:

Cobalt 60 3 Sealed Sources, 100 mc 300 millicuries each (iso Corp. Model Z-54)

As can be seen from this description on the license application, the user's license will contain limited information regarding the chemical nature of all the material used by the licensee. Information we were able to obtain from the license review related to the type of use, i.e. manufacturer, research laboratory, medical, industrial. In some cases material accompanied the license which was supplied by the applicant and yielded information about safety procedures, product production and material. Some licensees could be eliminated from our survey list at this point as it could be determined they were not waste generators.

A letter of explanation was sent to the interviewee prior to the telephone contact (see Appendix A). We were generally referred to the individual responsible for radiation safety at each of the institutions contacted. Information specifically requested during the interview related to the volumes of waste, packaging methods, chemical content, and disposal methods.

In addition to the telephone interviews, visits were made to National Institutes of Health (NIH), the Chem Nuclear Barnwell burial facility, and the South Carolina Department of Radiation Protection. The radiation safety

officer at NIH identified six departments of that institution which were contributors to the waste shipped from NIH to burial grounds. Five department chairmen were then contacted for further information regarding the specific chemical nature of the waste products generated in their divisions' activities.

Table 2-2 presents the interview list with indication of the type of waste shipped by each to commercial burial grounds.

TABLE 2-2

SELECTED INTERVIEW LIST

	Type Material Shipped for Burial					
	LIQUID	SOLID	BIOLOGICAL	INCINERATION	COMPACTOR	USER OF COMMERCIAL DISPOSERS
New England Nuclear	X	X	X	0	0	X
Meloy	X	X	-	-	-	-
Amersham	X	X	0	0	0	X
National Lead	0	0	0	0	0	0
Neutron Products	0	X	0	0	0	X
Detek	0	0	0	0	0	0
Victoreen Instru.	0	0	0	0	0	0
The Nucleus, Inc.	0	X	0	0	0	X
Teledyne	0	0	0	-	-	-
Naval Research Lab	0	X	0	0	0	X
N.I.H.	X	X	X	0	0	X
Walter Reed	X	X	X	0	0	X
Veterans Hosp.	X	X	X	0	0	X
John Hopkins	X	X	X	X	0	X
Georgetown U	X	X	X	X	0	X
Howard U	X	X	0	0	0	X
Baltimore Hosp.	X	X	X	0	0	X
Columbia Research	0	0	0	0	0	0
Litton Bionetics	X	X	X	0	0	X
Am. Red Cross	X	X	0	0	0	X
Hazelton Lab	X	X	X	0	0	X

X = Some Quantity
0 = None
- = No Information

2.2.1.3 Non-Fuel Cycle Waste Generators

The non-fuel cycle waste generators are defined as follows:

Academic Institutions

This category includes universities and colleges, junior colleges, vocational schools and secondary schools. Much of the material used for educational purposes will contain an amount of radioactivity which may be procured, handled, and used as exempt quantities by persons who are, therefore, not under U.S. Nuclear Regulatory Commission or State licensing requirements (10CFR30.14). Excluded from this category are universities with associated medical schools.

Hospitals

Included in this category are medical schools, teaching hospitals, and large and small hospitals. Large hospitals are defined as having more than 500 beds.

Medical Laboratories

Private physician-run laboratories performing *in-vitro* clinical assays such as radio-immuno assays, etc. These are not major research laboratories.

Private Physicians

This category includes physicians in private practice licensed to use radioactive materials in diagnosis or therapy either as sealed sources or as radiopharmaceuticals and *in-vitro* assays.

Radiochemical Manufacturers

These companies are licensed to manufacture and distribute byproduct material for licensed and license-exempt users. The products are primarily kits for radio-immuno assay or scintillation counting for biological research, clinical *in-vitro* assays, or nuclear medicine.

Research Laboratories

This group includes private and governmental laboratories engaged in biological research, environmental research, and materials testing.

Industry

This category includes manufacturers of testing equipment instrumentation and sealed sources, as well as users of these items.

Other

Public works, civil defense, and other governmental agencies, radiological consultants, veterinarians, etc. are included in this category. Materials used by this category are most likely to be in the form of sealed sources.

2.2.2 Chemical Characterization

2.2.2.1 General Background

The commercial waste handlers/disposers which were contacted, as well as the manager of a shallow land waste burial site, could give no specific information on the chemical nature of material buried in the commercial burial sites. The Radiation Shipment Records include information regarding radioisotopes and activity levels, physical form, and volumes only. Monitoring systems at the Barnwell burial site give no information as to the chemical nature and have been concerned only with radioisotope escape into the environment.

Discussion with the interview survey group served to identify the chemical nature of some of the material consigned to the burial sites, however, quantities were poorly defined. Further study and survey would be necessary to determine if the interview survey population is representative of the total population, and if there are major chemical constituents missing from the list compiled through interview survey. To determine the exact

chemical nature of all material consigned to the shallow land burial sites, records would have to be maintained which would show the chemical characterization of waste material disposed of by the waste generator at the burial site.

Two pieces of information were turned up in our survey, which are significant to the question of the chemical nature of materials going to the low-level burial grounds. These were:

(1) Where there is a prohibition in the burial ground license against receipt and burial of toxic chemicals, burial ground operators require a certification from the organization delivering the waste that it is non-toxic. The burial ground operators do not attempt to verify the validity of this representation, nor is it known by either the burial ground operators or the waste collection-disposal agents what the specific criteria for toxicity are. One might anticipate that the organizations generating waste with potentially toxic constituents would be required to develop some documentation to support the designation "non-toxic" which is required by the waste collection agencies and the burial ground operators as a prerequisite to accepting the waste. We found no evidence, however, that this is done.

(2) An unknown, but possibly significant, fraction of the wastes delivered as "radioactive waste" by institutional generators are in fact non-radioactive materials which are unidentified by the institutions. It could be inferred that such materials are disposed of in this manner because it is more convenient to opt for this type of disposal than disposal

through ordinary trash disposal routes.

2.2.2.2 Specific Radioactive Waste Constituents

Although the radiochemical manufacturers could not quantify the chemicals in their waste, a review of catalogs of products reveals a lengthy list of organic chemicals produced with various radioactive tagging. Any of these compounds might be found in the waste of a manufacturer as well as in the waste of the user of these compounds. One extensive catalog is abstracted in Appendix B. The complexity of identifying all the possible chemicals for toxicity analysis is shown by the introduction to this catalog which states:

> This section lists those compounds available from (manufacturer's name) which it is practicable to categorize. Our Radiochemicals Catalog includes in addition, a wide range of reagents, synthetic intermediates and other compounds not included in these categories. Our range of labelled compounds is continually being extended by the addition of new products. If the particular compound you need is not included in this listing this may mean only that it is not in sufficiently regular demand to include as a catalog item, and does not necessarily imply that it cannot be made. Inquiries for compounds not listed or for large amounts of standard items are welcomed.

The Maryland Report identified the nine most frequent nuclides appearing in institutional waste. The typical form of that nuclide is summarized in Table 2-3.

Other chemicals specifically identified by our interview survey are listed in Table 2-4.

TABLE 2-3

ISOTOPE TECHNICAL DATA,

MEDICAL USES*

Isotope	Typical Forms
^{131}I	Albumin, Sodium Iodide, Labeled Proteins, Iodohippurate, Rose Bengal
^{99}Tc	Sodium Pertechnetate, Serum Albumin, Technetium Sulfur Colloid, Technetium Polyphosphates, Technetium DTPA
^{3}H	Amino Acids, Nucleic Acids, Fats, Carbohydrates, Tritiated H_2O, etc.
^{32}P	Phosphoric Acid, Sodium Phosphate, Chromic Phosphate
^{125}I	Insulin, Serum Albumin, Sodium Iothalamate, Cortisol, RIA (Radio Immuno Assay) Kits, most hormones, etc.
^{35}S	Various Sulfate Salts, Labeled Drugs
^{67}Ga	Gallium Citrate
^{14}C	All, including Amino Acids, Nucleic Acids
^{51}Cr	Chromated Serum Albumin, Sodium Chromate

*See Appendix B

TABLE 2-4

SUMMARY OF IDENTIFIABLE CHEMICALS IN NON-FUEL CYCLE WASTES

Scintillation Vials	Other Liquids	Solid Waste	Biological Waste
toluene, xylene, sodium hydroxide; (with small amounts of methanol); aquasols, POP	50% is spent scintillation fluids. Other liquids are organic waste, alcohol, benzene, ethyl acetate, and RIA Kits which may contain any of the following compounds: ammonium sulfate, sodium barbital, sodium azide, ammonium salt, sulfonic acids, colloids, stannous polyphosphate, stannous glucoheptonate, amino sugars, amino acids, nucleosides, nucleotides, protein hydrolysates, pyruvic acid, $NaHCO_3$, anthracene compounds, phosphoric acid, iodoacetic acid, Bolton-Hunter reagent, iododeoxyuridine, sodium iodide, organic phosphates, orthophosphates, methionine, tritiated thymodine, ethidium bromide (intercalating dye), paradimethyl amino benzalide (PDAB), ethylene diamine tetra acetic acid (EDTA) additional possible liquid waste could be solutions of any of the labeled compounds found in Appendix B.	cellulosics, PVC plastics, rubber, glass, metal filings, other trash.	animal carcasses, cultures disinfected with Clorox[R], Beau Coup[R] (a phenol solution), or Wescodyn[R] (iodine base); or contaminated animal wastes.

2.2.3 Physical Form Characterization

Acceptance criteria of the individual burial sites for radioactive waste vary from site to site. The Department of Transportation (DOT) has the responsibility for establishing and enforcing regulations governing the packaging and transportation of hazardous materials. DOT and the Nuclear Regulatory Commission (NRC) establishes requirements for packaging and shipping licensed radioactive material. The prime objective is the prevention of damage to the surrounding environment during transportation.

The nature of the packaging and physical form of the waste are of importance to the study of chemical toxicity, as these factors will influence the rate of availability of the radionuclides to the environment.

2.2.3.1 Liquid Waste Material

The liquid waste materials include the following:

Scintillation Vials

Sealed scintillation vials are packaged and labeled separately from other liquid material. A standard DOT-approved 55 gallon drum is filled with 2000-3000 vials and vermiculite at a two to one ratio of vermiculite to liquid contained, and sealed. Some hospitals indicated they place the vials in a plastic bag before placing in the drum; others layer the vials and vermiculite.

Other Liquids

Treatment of other liquids varied but can be characterized as absorbed, solidified, or bottled.

Absorbed liquids were drained into a 30 gallon drum with varying portions of vermiculite. The 30 gallon drum was

placed in a 55 gallon drum, the remaining volume of which was filled with vermiculite.

A few waste generators used commercially prepared 30 gallon drums which contained material which would solidify the liquids deposited in the drum. Solidifiers identified were plaster of paris or cement. These 30 gallon drums were then encased in 55 gallon drums surrounded by vermiculite.

The last characterization, "bottled," was simply one to five gallon glass or plastic jugs filled with liquid waste and placed in vermiculite in a 30 gallon drum, then in a 55 gallon drum with vermiculite.

2.2.3.2 Solid Waste

This is typical trash which has had some radioactive contamination by the user. The trash is collected in 55 gallon drums until the drum is filled, then it is sealed and sent to the burial site. None of the interviewees compacted their trash prior to storage, although the Maryland Studies indicate it is often compacted. Typical contents were: empty bottles, rubber and plastic gloves, absorbent paper, glassware, PVC plastics, ion exchange resins, etc.

2.2.3.3 Biological

Animal carcasses are packaged and labelled separately from the other waste products. The carcasses are frozen until enough accumulate to fill a drum. They are sealed in plastic and packaged frozen in a 55 gallon drum with vermiculite. The interview survey identified only two large medical schools who incinerate animal carcasses (Table 2-2).

2.2.4 Volume Characterization

The total volume of waste sent to low level

commercial burial grounds by the non-fuel cycle population was 48,217 cubic meters in 1978 (NUS, 1979). Table 2-5 characterizes the volume of waste generated by type of user (as defined in Section 2.2.1.3) and by physical form (as defined in Section 2.2.4).

Our interview survey supported the Maryland Report findings that greater than 50% of the waste material from the medical community is scintillation vials or other liquid radwaste. The interview survey also confirms their finding that biological waste, i.e., carcasses, tissue cultures, are a small component of the total radioactive waste generated.

Table 2-5 was developed from three sources -- The Maryland Report (Beck, 1979), an NUS study (NUS, 1979) and our interview survey. The percentages for each user in the institutional/medical facilities and Universities were taken from the Maryland Report. The NUS study provided total volume for the institutional contribution to the waste and the percentages were applied to develop each user's contribution. Industrial and government/military total contribution was taken from the NUS study. Percentages of total volume for rad chemical manufacturers given in Table 2-5 were derived from our interview survey. A Booz-Allen report (EPA, 1973) gave generating figures for the typical radiopharmaceutical manufacturer as 6-12 drums/mo. Total for this industry was then derived using the total number of NRC Manufacturing and Distributing Broad Licenses (73) and an average waste production figure. Our interview survey found the waste from this category to have a much greater percentage of solid wastes and trash than the medical users and a significantly reduced percentage of liquid waste. The Booz-Allen report, which describes the output of one manufacturer as representative of pharmaceutical industry practice, states that the radioactive wastes are pumped directly to 10,000 gallon storage tanks for decay. Manufacturing residues and product rejects are given to an NRC licensed disposal service. Except for certain classified material, all governmental research laboratories used commercial disposal vendors and subsequent disposal in commercial burial grounds. Those using radioactive materials in biological research generated waste strikingly similar to the medical

TABLE 2-5

NON-FUEL CYCLE WASTE VOLUME CHARACTERIZATION

	USER	Liquid Scintillation Vials		Liquid Solidified & Absorbed Liquids		Dry Solid Waste		Biological Waste		Other	Total
		m^3	%	m^3	%	m^3	%	m^3	%	m^3	m^3
Institutional/Medical Facilities & Universities 1/	Medical Only	68	17.7	40	10.5	174	45.2	102	26.5		384
	Bioresearch Only	63	16.4	148	38.4	86	22.3	89	23.0		386
	Non-Bioresearch Only	43	22.3	19	9.9	97	50.8	33	17.1		192
	Medical and Bioresearch	4760	49.5	673	7.0	3318	34.5	875	9.1		9626
	Bioresearch & Non-Bioresearch	932	32.3	361	12.5	1422	49.3	167	5.8		2882
	Medical, Bioresearch and Non-Bioresearch	1506	26.1	767	13.3	3081	53.4	421	7.3		5775
	Rad-Chemical Manu. 2/	100	5	100	5	1803	90	0	0		2003
	Industrial 3/									20397	20397
	Gov't & Military 3/					6514		11		47	6572
	TOTALS	7472		2108		16495		1698		20444	48217

1/ Beck, 1979

2/ E. R. Johnson Survey

3/ NUS, 1979

schools and teaching hospitals. The interview survey identified no liquid waste generated by the industrial category and only one generator of solid waste.

Although growth projections are beyond the scope of this report, it should be noted that use of nuclear medicine is increasing and greater volumes of low level waste are to be expected from that area. Radiopharmaceutical use has increased five fold from 1960 to 1970 and EPA estimates an increase of seven fold may be experienced from 1970 to 1980 (Fledman, 1976). A pilot study of six hospitals' nuclear medicine trends shows an average increase in medical procedures using radiopharmaceuticals in excess of 17% per year (Fledman, 1976). The Maryland Report (Beck, 1979) shows an overall increase of 21% from 1975 to 1977 of the volume of radioactive waste shipped for burial by the institutional users.

Non-fuel cycle radioactive waste records kept by Chem Nuclear at Barnwell, South Carolina show marked growth trends. For example, Table 2-6 presents data taken from Chem Nuclear records which shows percentage increases of greater magnitude than the published material previously noted.

TABLE 2-6

VOLUME OF NON-FUEL CYCLE WASTE RECEIVED AT SOUTH CAROLINA BURIAL SITE BY MONTH

Month	Volume (ft^3)	% Increase
March 1975	12,000	--
March 1976	16,000	33.33
March 1977	25,000	56.25

Total volume of waste received at Barnwell showed percentage increases of 6.5% from March 1975 to March 1976 and 17% from March 1976 to March 1977. The increase from 1975 to 1976 can be attributed in part to the closing of the West Valley site in March of 1975; however, a further increase was observed from 1976 to 1977 and the above figures show an even greater jump for the non-fuel cycle contributors. We concluded that the non-fuel cycle waste accounted for much of the growth in total waste during these time periods. In spring of 1979 Barnwell began a prohibition on the disposal of organic liquid wastes. This prohibition will reduce the amount of non-fuel cycle waste disposed of at Barnwell, but should result in increases at the Beatty and Richland disposal sites.

2.3. Characterization of Fuel Cycle Waste

2.3.1 Physical Characterization

The fuel cycle refers to the facilities and operations that provide for the preparation of uranium and the fabrication of reactor fuel and the use of the fuel at a nuclear power plant. The many chemical and mechanical operations of the fuel cycle and their resultant wastes are commonly grouped as follows:

Mining and Milling of Uranium Ore - These operations include removal of ore from the ground and the extraction of the uranium therefrom. The wastes are low in activity and large in volume; waste is stored at the mill site.

Conversion - This is the production of UF_6 from yellowcake (U_3O_8) and is currently carried out at two commercial plants using different production processes. The dry hydrofluor process used by the Allied Chemical plant at Metropolis, Illinois, produces solid residues and miscellaneous trash which it ships to a commercial burial site. The Kerr-McGee plant in Sequoyah, Illinois produces mostly liquid effluents, primarily the solvent extraction circuit raffinates,

which are impounded in ponds onsite. The solid waste materials from the Kerr-McGee process are buried onsite. Combustible air filters and laboratory and cleanup wastes are incinerated and the uranium recovered .

Enrichment - The amount of solid radioactive waste generated by gaseous diffusion plants is quite small and currently no waste is shipped to commercial burial sites .

Fuel Fabrication - Wastes produced from the fuel fabrication process are the liquid stream containing calcium fluoride and uranium, resulting from the conversion of UF_6 to UO_2, and the solid wastes consisting of filters, paper, piping, pumps, motors, etc. The liquid waste stream is precipitated in ponds and lagoons onsite. Combustible trash is incinerated and the ash subjected to uranium recovery when levels of uranium contamination make this method economical . Other solids are compacted and shipped offsite for shallow land burial.

Light Water Reactors (LWR) - The nature and volume of wastes produced in boiling water reactors (BWR) and in pressurized water reactors (PWR) differ slightly because of the different treatment systems. In a BWR, the main condensate is processed through a cleanup system and a side stream of the primary coolant is processed through a demineralizer. In a PWR, the primary coolant is always in the liquid state and is continuously purified by passing a side steam through filters and demineralizers. Boric acid is added to the primary coolant of a PWR as a neutron absorbing control device. This is further described in Appendix C.

Reprocessing, Spent Fuel Storage, Decommissioning These activities were not included in this report as the majority of these wastes either have not been identified yet or will be high level wastes requiring different disposal methods than Shallow Land Burial.

2.3.2 Chemical Characterization

As a consequence of nuclear power fuel cycle operations, radioactive wastes are generated. A good overall description of these wastes is given in ERDA's exhaustive technical alternatives document (ERDA, 1976). The solid trash waste is miscellaneous dry solids consisting of paper, plastic, and discarded clothing which is generally compacted into 55 gallon drums or boxed for shipment to burial grounds. It is not likely that these wastes will be of any concern in this study of chemical toxicity since they are, of themselves, innocuous material and the contamination level is quite low.

On the other hand, the other wastes are of a diverse chemical nature and contain a broad spectrum of radionuclides. These wastes result from the treatment of liquid streams in the reactor plants. The processes applied to liquid reactor streams and producing wet solid wastes are filtering, demineralizing (ion exchange), evaporating, and (less commonly) centrifuging and reverse osmosis. Prior to these processes the various streams in a light water reactor are classified and segregated or collected according to their radioactivity and dissolved solids content in order to combine streams having similar characteristics and requiring similar treatment. Streams of low dissolved solids content ("clean" wastes) can be purified directly by demineralization. On the other hand, streams of high dissolved solids content ("dirty" wastes) are unsuitable for demineralization; they are treated by evaporation, producing a bottoms slurry that is concentrated in solids, and a purified, overhead stream that can be purified further by demineralization.

2.3.2.1 Conversion and Fuel Fabrication

Conversion of U_3O_8 to UF_6 for enrichment is accomplished by two generally different processes which lead to somewhat different types of waste. In one process, the uranium is dissolved in nitric acid, and the solution purified by solvent extraction; the uranium is precipitated, converted to UO_3 and then to

UO_2. The oxide is then converted to UF_6 by hydrofluorination followed by fluorination. In the other process, the uranium is converted initially to UF_6 which is purified by distillation. Wastes from both of these processes are radioactive by reason of the contained residual uranium which is not economically recoverable, and the separated uranium decay chain elements. In terms of quantity, the largest amount of the waste is CaF_2 from lime treatment of waste solutions. These wastes are sent to settling and evaporation ponds. Other wastes, such as loaded filters, contaminated clothing, etc. are disposed of by shallow land burial. Process wastes from the solvent extraction process will be generally similar to those from the fuel fabrication plants, as discussed below.

Fuel fabrication plants, convert UF_6 to UO_2 using any of several processes involving either a direct conversion of UF_6 to UO_2 by steam in the presence of hydrogen, or a solution process involving the hydrolysis of UF_6 to UO_2F_2 followed by precipitation of the uranium with ammonia, yielding ammonium diuranate ($(NH_4)_2U_2O_7$); this is calcined in the presence of hydrogen to UO_2. Major wastes from this are a mother liquid from the $(NH_4)_2U_2O_7$ precipitation, from which ammonia may be recovered for reuse, and the scrubber liquids from the calciner off-gas treatment system, after filtration to remove the insoluble uranium sludges. Both liquid streams contain excess fluoride, ammonia, and metallic fluorides present initially as impurities in the process streams or introduced by corrosion of the process equipment. Off-gas scrubber sludges contain high percentages of uranium and may be reintroduced into the process after appropriate treatment. Other metallic impurities which may be present in these sludges and precipitates include iron, copper, magnesium, and zinc - all at low concentrations.

These plants generate rather little waste for off-site disposal. As noted, the principal waste is a fluoride-bearing liquid stream which is treated with lime in a settling/evaporation pond, which results in precipitation of CaF_2 and uranium; the uranium results from a process loss of about 0.1 percent of the uranium feed. In order to recover the uranium, fuel fabrication facilities commonly incinerate combustible wastes carrying any appreciable level of contamination and subject the ash to uranium recovery (Perkins, 1975). Offsite waste disposal is used for sludges and filters and other residues which are not suitable for uranium recovery, and for miscellaneous contaminated trash. In addition to the usual types of materials in such trash (clothing, gloves, shoe covers, etc.), fabricators report that they dispose of contaminated process equipment and firebrick removed from sintering furnaces during overhaul of the furnaces.

Although the UF_6 conversion process described above, which goes through the ammonium diuranate solid, is the one most commonly used, an alternative process based on an intermediate solid of tetra ammonium uranyl carbonate $(NH_4)_4UO_2(CO_3)_3$, and an associated waste treatment process has been reported and is claimed to produce effluents which may be safely discarded directly to the environment (Doknzoguz, 1974). In this process, the original effluents contain large amounts of NH_4^+, $CO_3^=$, F^-, and a small amount of U; CO_2, NH_3, H_2O, and U are recovered and treated effluents along with $CaF_2/Ca(OH)_2$ solids are discharged.

2.3.2.2 Light Water Reactor (LWR)

Low level wastes from LWR's comprise spent ion exchange resins, evaporator bottoms concentrates, contaminated boric acid concentrates, filter sludges, and miscellaneous contaminated trash. The ion exchange resins may be either anionic or cationic resins from the demineralizer

systems, and are in general either sulfonated or aminated organic polymers; modified polystyrenes are typical substrates. The ion exchange resins may be simply dewatered and packaged for shipment to the burial ground, or they may be solidified in an insoluble matric. Commonly used solidification agents are portland cement, with or without bentonite or vermiculite, and urea-formaldehyde resins; the latter contain, in addition to the organic monomers, low concentrations of alkali metal bisulfates. Other solidification agents which may be used in the future are asphalt and vinyl ester styrenes.

Evaporator concentrates include the spent regenerant solutions from demineralizers (largely sodium sulfate), concentrated coolant blowdown containing boric acid, any non-volatile residues from pH-adjusting chemicals used in the coolant, and any non-volatile radioactive species which may have reached the evaporators. Evaporator concentrates are solidified prior to shipment and disposal. Filter sludges include precoat material such as diatomaceous earth, powdered ion exchange resins ("Powdex"), activated corrosion products removed from coolant, together with radioactive ions captured from the filtered liquid. Filter sludges may be either dewatered or solidified as described above.

The miscellaneous contaminated trash comprises the same general types of items described elsewhere for other facilities - protective clothing, tools and obsolete or non-functioning equipment. The principal difference lies in the fact that the contamination from the LWR contains fission product and activation radioactivity.

Detailed chemical composition data are not available on the bulk of the materials likely to be encountered in low level wastes from LWRs. These wastes obviously consist of the chemicals, filter material, and ion exchange resins used to treat the process streams and of the material removed from those streams.

The ion exchange resins contribute approximately 7% of the reactor-generated wastes, and the general composition of these has been identified. The following tabulation gives some specific information on resins used at a particular PWR:

Service	Rohm & Haas No.	Type
Primary System	IRN 217	Cation-anion
Deborating	IRN 78	Anion
Evaporator Condensate	IRN 150	Cation-anion
Cation Demineralizer (for corrosion products)	IRN 77	Cation
Spent Fuel Pool	IR 150	Cation-anion

These resins are based on a copolymer of styrene and divinyl benzene. The cation resin (IRN-77) is sulfonated with sulfuric acid to put a $-SO_3H$ radical on the benzene ring; the anion resin (IRN-78) is chloromethylated then treated with trimethylamine and sodium hydroxide to give an anion exchanger in the hydroxide form. The cation-anion resins are mixtures of these two resins. Other resin substrates include polystyrene, phenolic, polyacrylic, and epoxy-amine.

The material to be removed from the liquid streams include the possible fission products from leaking fuel elements, corrosion products, water treatment chemicals and, in the case of some PWRs, boric acid. Table 2-7 (Mergan, 1975) gives some data on primary water chemistry in a PWR for before and after processing.

TABLE 2-7

PRIMARY REACTOR COOLANT WATER CHEMISTRY

	Before Processing	After Processing
H_2	< 35 cm^3/ℓ	-
H_3BO_3	10 - 18,000 ppm	< 10 ppm
Cl^-	0.15 ppm	0.15 ppm
F^-	0.1 ppm	0.1 ppm
O_2	0.1 ppm	0.1 ppm
Cruds	10 mg/ℓ	-
Corrosion Products	< 10 ppm	-
pH	4.5-10.5	6.8
Non-gaseous activity	< 10 Ci/m^3	10^{-7} Ci/m^3 (Distillate) 10^{-1} Ci/m^3 (Concentrate)

The constituents cited in Table 2-7 (except for the gaseous elements) will appear with the solid wastes, either adsorbed on the spent resins, in the solidified evaporator concentrates, or in the filter sludges. Radioactive species will be present either as absorbed ions on the resins, or as chemical compounds in the concentrates or sludges. No specific experimental work on the composition of these materials appears to have been done, but certain inferences can be drawn from the environment of the reactor cooling system.

Calculated concentrations of radioactive species in the coolant have been presented in the Final Safety Analysis Report for a PWR (FSAR, Davis Besse). The values for fission product levels were calculated from the anticipated equilibrium spectrum of fission products in the fuel, using conservative assumptions based on experience with similar reactors, for the transport from fuel to coolant. Average values were based on the assumption of 0.1% failed fuel during the cycle and maximum values were based on 1% failed fuel. Table 2-8 presents the results of these calculations for the ionic radionuclides, i.e., those appearing in the solid state.

TABLE 2-8

AVERAGE AND MAXIMUM ANTICIPATED FISSION PRODUCT ACTIVITIES IN REACTOR COOLANT AND CLEAN RADWASTE SYSTEM FUEL

Isotope	Average, μCi/ml		Maximum, μCi/ml	
	Coolant	After Demineralizer	Coolant	After Demineralizer
Rb-88	0.270	2.70×10^{-3}	2.70	2.70×10^{-2}
Sr-89	4.51×10^{-4}	4.51×10^{-6}	4.51×10^{-3}	4.51×10^{-5}
Sr-90	1.46×10^{-5}	1.46×10^{-7}	1.46×10^{-4}	1.46×10^{-6}
Sr-91	2.85×10^{-3}	2.85×10^{-5}	2.85×10^{-2}	2.85×10^{-4}
Sr-92	8.72×10^{-4}	8.72×10^{-6}	8.72×10^{-3}	8.72×10^{-5}
Y-90	1.01×10^{-3}	1.01×10^{-3}	1.01×10^{-2}	1.01×10^{-2}
Y-91	5.66×10^{-3}	5.66×10^{-3}	5.66×10^{-2}	5.66×10^{-2}
Mo-99	0.412	0.412	4.12	4.12×10^{-2}
I-131	0.323	3.23×10^{-3}	3.23	3.23×10^{-2}
I-132	0.225	2.25×10^{-3}	2.25	2.25×10^{-2}
I-133	0.378	3.78×10^{-3}	3.78	3.78×10^{-2}
I-134	4.58×10^{-2}	4.58×10^{-4}	0.458	4.58×10^{-3}
I-135	0.190	1.90×10^{-3}	1.90	1.90×10^{-2}
Cs-134	0.409	0.409	4.09	4.09
Cs-136	7.40×10^{-2}	7.40×10^{-2}	0.740	0.740
Cs-137	1.27	1.27	12.7	12.7
Cs-138	7.34×10^{-2}	7.34×10^{-2}	0.734	0.734
Ba-137m	1.17	1.17	11.7	11.7
Ba-139	7.60×10^{-3}	7.60×10^{-5}	7.60×10^{-2}	7.60×10^{-4}
Ba-140	5.63×10^{-4}	5.63×10^{-6}	5.63×10^{-3}	5.63×10^{-5}
La-140	2.25×10^{-4}	2.25×10^{-6}	2.25×10^{-3}	2.25×10^{-5}
Ce-144	5.18×10^{-5}	5.18×10^{-7}	5.18×10^{-4}	5.18×10^{-6}

The activity removed by the coolant demineralizer will appear with the spent resin, if a non-regenerable ion exchange system is used, or with the evaporator concentrates if a regenerable system is used. In the latter case, the fission product cations would be expected to be present as sulfate salts, and the anions as sodium salts.

Corrosion products in reactor coolant may become activated when passing through the core (or originate from core material). The most important corrosion products are ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{59}Fe, ^{59}Co, ^{60}Co, and ^{95}Zr. The corrosion product activity is dependent on many factors, including the type of reactor plant and the materials of construction.

It would be expected that the corrosion products would be present in the solid wastes as either oxides or hydrated oxides; they are most likely to be in the filter sludge,if a non-regenerable demineralizer is used on the initial reactor coolant purification; if a regenerable ion exchange system is used, they would be expected to be in the cartridge filters or in the evaporator concentrates. The evaporator concentrates from the primary system also contain boric acid and sodium tetraborate while those from the regeneration of resins are dominantly sodium sulfate and ammonium sulfate.

The wastes from boiling water reactors (BWR) are generally similar to those from PWR's, even though details of the radwaste and coolant cleanup systems of the two reactor types differ substantially. It may be assumed that the radioisotope profiles from the two reactors do not differ markedly and, other parameters being equal, the quantities of radioactive materials are similar. The Atomic Industrial Forum has concluded, however, that the BWR would produce approximately 37 percent more volume of waste than the PWR. Except for the absence of boron compounds from BWR wastes, however, no significant differences in the chemical composition of the two wastes would be expected, (see Appendix D).

2.3.3 Physical Form Characterization

Typical packaging and physical form of fuel cycle wastes shipped to burial site are discussed in the following paragraphs.

2.3.3.1 Conversion

CaF_2 solids containing natural uranium and daughters are packed and shipped in standard 55 gallon steel drums. Miscellaneous uranium contaminated wastes are also packed in drums (Mann, 1975).

2.3.3.2 Fuel Fabrication

Trash which does not have a uranium concentration worthy of recovery is packaged in fiberboard boxes after compaction. A 50% volume reduction is achieved by compaction. Bulk shipments of non-compactible materials, such as pipes, motors, fire bricks, HEPA* filters, and valves are also packed in wooden boxes. These boxes are produced according to DOT specifications. Typical compacted materials are shoe covers, wood, cardboard, cloth, rubber gloves, mop heads. One fuel fabricator indicated that 100% of the compacted material could go to the incinerator if the costs of disposal at burial sites became more expensive than incineration.

2.3.3.3 LWR Wastes

The LWR wastes are packaged as follows:

Solidified Liquid - Liquid waste solidified by mixing with cement or urea-formaldehyde polymer is packaged in 55 gallon drums or larger cask liners at most BWRs and PWRs. Fifty percent of the solidified liquid waste requires shielding (AIF, 1976).

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*High Efficiency Particulate Air

Demineralizer Resin - Deep bed demineralizer resin is packaged in 55 gallon drums or cask liners. Common practice is to pump or syphon excess water from the shipping container. Only a few LWRs solidify the resin for shipment off-site. All waste is shipped in shielded containers.

Filter/Demineralizer Sludge and Cartridge Filters - Cartridge filters are packaged in small liners or 55 gallon drums or may be placed in shielded containers directly on removal from service. The filter-demineralizer sludge is processed through a centrifuge and/or a phase separator to remove the liquid from wastes before packaging. Solidification of the sludge is performed at only three out of 14 operating BWRs (AIF, 1976). Shielding for the filter/demineralized sludge varies from three inches of steel to four inches of lead.

Contaminated Trash - Most plants package contaminated trash by compacting it in 55 gallon drums. Several plants, however, use plywood boxes without compaction. Plywood boxes are also used for contaminated equipment which is too large for the drums and does not lend itself to compaction. Several plants use cardboard boxes and plastic sheeting to package the HEPA filters from ventilation systems. Because of the low specific activity and low radiation levels, contaminated trash is shipped and buried without shielding.

2.3.4 Volume Characterization

2.3.4.1 Conversion

The conversion process at the Allied Chemical plant produces 4,286 55 gallon drums per year of CaF_2 (Mann, 1975). Other trash contributes up to 600 drums/year. Total volume shipped to burial sites from this sector is 1,007 m^3/yr.

2.3.4.2 Fuel Fabrication

Two fuel fabricators, General Electric and

Westinghouse, ship 1,608 m^3/yr. and 518 m^3/yr., respectively, to shallow land burial sites. This industry's total is extrapolated to be 3,000 m^3/yr. Westinghouse indicated that 30% of the total was compacted trash and the remainder large equipment, fire bricks and pumps; however, General Electric defined 60% of their waste as compacted trash with the remainder large equipment, etc.

2.3.4.3 Light Water Reactors (LWR)

Waste generation figures for the LWRs are given in most literature as a function of the electrical generating capacity.

A study performed by NUS for the Office of Nuclear Waste Isolation (ONWI), Battelle Memorial Institute, completed in March 1979, determined the characteristics and quantities of low level radioactive wastes generated and disposed of by light water power reactors (Phillips, et al., 1979). The quantities for each type LWR are summarized in Table 2-9.

TABLE 2-9

ANNUAL WASTE GENERATION

($ft.^3$/MWe/yr)

(Phillips, et al., 1979)

PROCESS	BWR		PWR	
Type Waste	Deep Bed Condensate Polishing System	Precoat Filter Condensate Polishing System	Without Condensate Polishing Systems	With Condensate Polishing Systems
Spent Resin	0.64-5.8[1/]	NA	0.94	0.32
Concentrated Liquids	12.7	0.026	3.90	4.8
Sludge and Filter Precoat	5.4	7.7	0	0.15
Cartridge Filters	0.09	0.09	0.39	0
Trash	11.5	11.5	11.5	11.5
Total	30.33-35.49[1/]	19.3	16.73	16.77

1/ First figure represents fresh water condenser cooling; second figure represents sea water condenser cooling.

NRC supplied data giving a summary of waste projections. These are shown in Table 2-10 by plant type.

TABLE 2-10

REACTOR RADWASTE VOLUME BY TYPE
(Percent of Total)

	PWR	BWR
Liquid	39	36
Resin	5	12
Sludge	2	24
Trash	53	26

The NUS study estimated the total volume of waste from nuclear power plants in 1978 to be 35,563m^3.

2.4.0 Burial Site Monitoring Studies

Monitoring of ground water around burial sites is directed towards identifying only radioisotope species and concentrations. Studies which have been done of the radiochemical, inorganic and organic constituents of the trench water at Maxey Flats, Kentucky, burial site by Columbo and his associates at the Brookhaven National Laboratory (Columbo, 1977), and the West Valley, New York, burial site by the New York State Department of Health (Husain), are, however, of interest to this project. Analyses of the trench water will provide a limited clue to the nature of some of the materials present in the burial trenches, however, caution must be used in extending the results of those studies to a definitive description of the chemical nature of material consigned for disposal at the burial site.

Historical experience with burial ground sites indicates that changes in packaging requirements and general housekeeping procedures have occurred. Thus, trench water samples at old burial grounds may not be indicative of material currently being disposed in accord with present day container requirements.

Each study expressed concern regarding the impact of the chemical constituents on the mobility of the radionuclides and the complexing ability that exists in the trenches. Correlation of the trench water analyses with the chemical characterization of the non-fuel cycle and fuel cycle waste generators will be of use in making recommendations regarding burial site procedures and requirements. However, the tabulation of chemicals from trench water will not discriminate between the buried material and what occurs naturally on the site. Columbo further notes that "since wastes coming into the burial site were not segregated, it can be assumed that practically every trench at Maxey Flats contains varying concentrations of waste types". Thus trench water analyses will not identify the source of the chemical or the quantity of it which may be available from buried material, nor will it necessarily give any information as to the manner in which the waste was prepared for final disposition.

2.4.1 Maxey Flats, Kentucky

Trench water samples were collected in September 1976 at Maxey Flats burial ground site for a detailed analysis of radiochemical, inorganic and organic constituents by Columbo and his associates at Brookhaven National Laboratory. The results of the radiochemical and inorganic analyses are presented in Columbo, et al., 1977.

The organic compounds identified are listed in Table 2-11. Columbo, et al., notes that the list of organics is far from complete and that no effort was made to quantify the organic compounds. Future study will focus on more detailed qualitative and quantitative analysis. Columbo,et al., atributes the organic compounds to solvents, decontamination liquids, and involvement of microbial activity producing the low molecular weight organic acids and CO_2 in several trench waters.

TABLE 2-11

SELECTED ORGANIC COMPOUNDS FROM TRENCH WATERS AT MAXEY FLATS

ALCOHOLS

Cyclohexanol
2-Butanol
2-Methyl-2-butanol
Methylcyclohexanol
2-Ethylhexanol
Diacetone alcohol
1-Octanol
3,3,5-Trimethyl cyclohexanol
Borneol
α-Terpineol

AROMATIC HYDROCARBONS

Toluene
Naphthalene
p-Xylene
Biphenyl

ALDEHYDES AND ACETALS

Paraldehyde
1,1-Diethoxyethane

ALIPHATIC HALOGENATED HYDROCARBONS

1,1,1-tricholoroethane

ETHERS

bis(2-Chloroethyl)ether
1,4-Dioxane
Tetrahydrofuran
bis(2-Chloroethoxy)methane
Vanillin

ESTERS

bis(2-ethylhexyl) adipate
Di(iso-octyl)adipate
Dioctyl adipate
Diethyl phthalate
Dibutyl phthalate
Dioctyl phthalate
Diisooctyl phthalate
Di-2-ethylhexyl phthalate
Tributyl phosphate
Triethyl phosphate

PHENOL AND PHENOLIC COMPOUNDS

Cresols (ortho, para, and meta)
4-tert-Butyl phenol

ORGANIC ACIDS

Benzoic acid
Formic Acid
Phenylacetic acid
Oxalic acid
Toluic acid
Stearic acid
Phenylhexanoic acid
Phenylpropionic acid
4-Hydroxy-3-methoxy benzoic acid

KETONES

Methyl isobutyl ketone
d-Fenchone

2.4.2 West Valley, New York

Husain and his associates at the New York State Department of Health have analyzed trench water samples obtained (1975-76) from the waste burial ground at West Valley, New York. Their objectives were to (1) quantitatively identify the radionuclides of greatest significance to human health and (2) obtain data for predictive modeling of radionuclide movement.

Table 2-11 lists the organic chemical constituents presented by Husain as preliminary measurements. Husain makes the following observation:

> "The major components of the dichloromethane fraction were cresol, aromatic ketones, and xylyl butanoic acid, whereas the hexane fraction was dominated by phthalate ester and tributyl phosphate. Many constituents in the hexane fraction were likely derived from buried cleaning agents, germicidal cleansers, surfactants, and paints. The aromatic ketones, xylyl butanoic acid, and humic acid residues were probably naturally occurring breakdown products of living matter."

A comparison of concentrations of nonradioactive chemical species at West Valley was made with values for sanitary land fills in Pennsylvania, Illinois, and Wisconsin. Husain notes that these values are "remarkably similar" and that the "appreciable concentrations of organic complexing agents at West Valley are representative of anaerobic decomposition products anticipated for sanitary landfills". In the light of the observation of Husain regarding the similarity of chemical species at the burial grounds and at sanitary landfills, it is clear that these analyses provide limited information regarding the assumed unique nature of the radioactive waste burial grounds as far as potentially toxic releases are concerned. They are, however, useful starting points for evaluating the possibility of toxic releases from these burial sites.

2.5.0 Summary

2.5.1 General

Approximately 80% of the waste being delivered to shallow land waste burial grounds can be reasonably accurately characterized as to its chemical composition, given the sources of the waste and the treatments given it at the source. There is, however, no requirement that the waste be described by the originator in terms of its chemical composition and as a consequence, only the radioisotopic nature is identified on shipping papers and burial ground records. A requirement that limits chemical toxicity of radioactive wastes to a level no higher than the radiotoxicity of the material is incorporated in several, if not all, of the waste burial licenses; it might be inferred that this requirement would lead to some identification in the shipping records of the chemical nature of waste transferred for burial. It appears, however, that this requirement is met by a certification from the originator that the waste is non-toxic, without any further supporting information. A recommendation was made by Clark in 1973 that waste burial records include

> "(t)he chemical composition of each shipment. The identification of the chemical composition normally specifies the elemental composition. This should be done when possible; however, with some shipments, e.g. carcasses, it is impossible to identify the elemental composition such as a carcass.
>
> "For shipments in which the chemical composition cannot be identified, the shipper should identify the shipment by the name of the item being shipped and, the most chemically toxic material associated with the radioactive waste and the concentration of this toxic material."

These recommendations do not appear to have been implemented. In order to develop a complete assessment of the chemical aspects of the waste, such information as Clark has called for must be available. It has been suggested that purchasing records of institutions be examined for listings of chemicals being used in the institutional

activities; this is believed to be inappropriate, as it would reveal little concerning the ultimate fate of these materials, and would not provide identification of the materials disposed of in the radioactive waste.

Another source of uncertainty in identifying the chemical character of the waste and assessing its chemical toxicity potential lies in the observation that some institutions appear to dispose of other than radioactive materials via the radioactive waste route. While no specific and corroborable data could be obtained on this point, it is clear that material which is not suitable for disposal by other means should not be thrown in with radioactive waste without proper documentation. Prime offenders in this area appear to be the non-fuel cycle generators, specifically the small hospitals. Given the evidence of growth of waste volumes from the non-fuel cycle community, disposal practices at these institutions need further examination.

Collectively, the trench water analyses by Brookhaven and New York State Department of Health and the chemical identification of the waste generated by the fuel cycle and non-fuel cycle institutions identified herein will serve in the evaluation of burial site procedures and requirements. From this information, development of recommendations regarding those requirements will be made. It is important to observe those cautions previously mentioned in connection with use of the trench water studies.

2.5.2 Non-Fuel Cycle Waste

The volume of waste generated by the non-fuel cycle industry is approximately 50% of the total waste consigned for shallow land burial. Of this waste, 50% of the medical and research community's waste is scintillation vials, predominately filled with toluene, or other liquids absorbed on solids or otherwise solidified as described in Section 2.2. The liquids other than spent scintillation fluids are primarily organic waste.

Solids are typical trash similar to the fuel cycle trash waste, but contaminated with the radioisotopes used for research. The medical, bioresearch, and academic communities contribute an estimated 25% of the total volume of waste. Biological or animal carcasses are a small percentage of total volume and are identified by separate packaging. Radiochemical manufacturers produce about 10% of total volume, but the majority (90%) of their waste is solids or trash. Industrial users are reported to contribute 24% of the total volume (NUS, 1979). Packaging of waste for shipment and burial was found to be uniformly in 55 gallon drums with vermiculite for absorption of liquids and little compaction of solids.

2.5.3. Fuel Cycle Waste

Waste reaching burial grounds originate in the conversion operation, in fuel fabrication, and in reactor operation. The two former sources produce waste contaminated only by naturally radioactive substances; volume appears to be of the order of 4000 cubic meters per year. Reactor wastes include fission product radioisotopes; volume appears to be of the order of 35,560 cubic meters per year in 1978.

The conversion and fuel fabrication operations generate large quantities of uranium-contaminated calcium fluoride; much of this is still at the plant sites in settling/evaporation ponds. Some is shipped to burial grounds, along with contaminated protective clothing (cotton fabric, polyvinyl chloride plastic, and rubber), wipes (cellulose), uranium contaminated filters (cellulose or glass fiber, wood frames) and obsolete equipment. Reactor operations generate large quantities of spent ion exchange resins (modified organic polymers), filter sludges (powdered ion exchange resins, diatomaceous earth), evaporator concentrates (largely sodium and ammonium sulfates, solidifed), spent cartridge filters, and contaminated trash. The radioactivity in these wastes is mixed fission products.

Packaging for burial is in standard steel drums; sealed steel cylinders; concrete, cardboard, or wooden boxes, depending on the nature and radioactivity level of the material. All liquids

are solidified; cement and/or urea-formaldahyde are the most widely used solidifying agents.

The volume of fuel cycle wastes represents approximately 43 percent of the total waste going to the waste burial grounds.

2.5.4 Summary Table

Table 2-12 presents the characterization of the non-fuel and fuel cycle waste by type, prime chemical identity, generator rate and packaging.

TABLE 2-12

SUMMARY: NON-FUEL & FUEL CYCLE WASTE CHARACTERIZATION

Source	Type	Chemical Identity	Generation Rate m^3/yr. (1978)	Disposal Packaging
Conversion	Residue	CaF_2 with U contamination	900	55 gallon drums
	Trash	Cellulosics, PVC plastics, Metals	100	"
Fabrication	Mixed trash equipment, etc.	Metals, fire bricks, charcoal with contamination of UO_2, U_3O_8, UO_3	3,000	Fiberboard and wooden boxes
Light Water Reactors	Ion Exchange Resins	Polystyrene, phenolic, polyacrylic, epoxy-amine	2,500 (a,b,c)	Solidified* or Dewatered, 55 gallon drums, shielded cask liners
	Evaporator Concentrates	Sodium and ammonium sulfates	9,970 (a,b,c)	Solidified* 55 gallon drums, shielded cask liners
	Filter Sludges	Powdex, diatomaceous earth	4,630 (a,b,c)	55 gallon drums, shielded cask liners
	Trash	Cellulosics, plastics, metals asbestos	16,650 (a,b)	55 gallon drums and fiberboard and wooden boxes
	Irradiated Components	Control rod poison curtains	1,800 (a,b)	
Medical and Institutional	Biological	Carcasses, animal waste cultures	1,687 (d)	55 gallon drums
	Solidified or absorbed liquid	Toluene, alcohol, benzene, etc vermiculite	2,008 (d)	30 gallon drum within 55 gallon drum
	Scintillation Vials	Toluene, vermiculite, glass, PVC plastic	7,372 (d)	55 gallon drums
	Dry Solid Trash	Cellulosics, PVC plastics, glass, metals	8,178 (d)	55 gallon drums
Rad Chemical Manufacturers	Liquid and Solids miscellaneous trash	Toluene, glass, vermiculite, cellulosics, PVC plastics, miscellaneous tagged organic compounds and residues	2,003 (d)	55 gallon drums
Government & Military	Biological Wastes, Dry Solids, Solid Sludge		6,572 (b)	
Industrial			20,397 (b)	

* Solidification agents: commonly urea formaldyhyde, portland cement.

(a) 1978 Generation Rates (c) NRC Data
(b) NUS, 1979 (d) Table 2-5

3.0 CHEMICAL TOXICITY OF WASTES DISPOSED IN LOW-LEVEL WASTE BURIAL SITES

3.1 Concepts of Chemical Toxicity

Chemical toxicity differs from that of radiologic toxicity. Radiation exposure can produce ions in tissues by absorption of ionizing energy. This absorption of ionizing radiation yields a variety of general responses that can be characterized chemically as the production of peroxides, free radicals, biological polymers, and modification of small molecules by energy absorption. By comparison chemical toxicity is characterized by more specific biological responses to exposure and depends on the physical and chemical properties of the particular substance. A chemical substance shows unique interactions with a living organism while the effects of low-level radiation depend on generalized interactions at the whole body or target organ level. In developing management and control guidelines for hazards presented by low-level waste burial sites, the chemical toxicity of a substance and its mobility or persistence are particularly significant.

In this section some basic concepts in chemical toxicity are discussed. These concepts include the types of effects which are studied, factors which may influence toxicity, the types of studies commonly used in characterizing the toxicity of a substance, and the significance or utility of information gained from such studies. In section 5.0 the application of this information to evaluating hazards from environmental exposures for a human population will be discussed, and finally a discussion of the toxicity for specific compounds from burial sites will be presented. An understanding of chemical toxicity concepts is essential to evaluation of relative hazards of chemicals and low-level wastes in burial sites.

3.2 Data Requirements for Hazard Evaluations

In making hazard evaluations, the essential consideration is the likelihood that a hazard will be expressed in some fashion. This expression of hazard could be in the form of an adverse effect on human health, an undesirable ecological impact, or a decrement in environmental quality. Independent of the effect, there is a need to develop information to

express such hazards in commensurate and quantitative terms to allow meaningful comparisons. For example, the determination of the degree of hazard in quantitative terms would provide a basis to compare various waste disposal and risk management options.

3.2.1 Exposure and Adverse Effects

Relevant factors to be considered are those related to exposure and adverse effects. These are the population, ecological system, or environmental quality at risk, the severity of the potential effect (immediate versus delayed, reversible versus irreversible, sensitivity of individuals), the dose-response relationship involved, and extent of exposure. In addition, there is a need to develop information on dose-response and to consider the use of a variety of methodologies for evaluating exposure and adverse effects data. However, frequently there is a paucity of information on the toxicology, distribution, concentration, and population or system at risk, and quantitative assessments of necessity are often based on substitute information to estimate the associated hazards. Information on relevant factors and substitutes for these in hazard assessments is indicated in Table 3-1.

The data collected needs to be evaluated by a scientific weighing of evidence. Important issues to be considered include:

- Data on carcinogenicity, mutagenicity, teratogenicity, or other reproductive effects.
- Corroborative or conflicting results between various historical reports, epidemiologic studies, animal toxicologic studies, clinical reports, human dose-response investigations, etc.
- Validity of experimental design, methodology, statistical analysis, etc.
- Controversy, contradictions, omissions, gaps in research.
- Range, precision, and accuracy of sampling and analytical methods.
- Interferences.

TABLE 3-1 DATA REQUIREMENTS FOR HAZARD ASSESSMENTS

Relevant Factors	Substitutes
Exposure	
Intensity Extent Duration	Disposal Data Volume of Distribution Consumption/dispersive use Transport Off-site, Residence Time
Uptake Absorption Persistence Mobility/Transport	Physical-Chemical Properties Molecular structure Degradation (photodecomposition, microbial oxidative, hydrolytic) Solubility/partition coefficient (lipid, H_2O) Volatility
Adverse Effects (Acute/Chronic)	
Human/Mammalian Clinical Laboratory studies	Acute Toxicological Studies (e.g., LD_{50}, LD_{L0}) Chronic Studies (e.g., carcinogenicity)
Environmental Laboratory/field studies Single species Multi-species/ecosystem	Predictive Acute and Chronic Toxicology Based on Physical/Chemical Properties

- Sources of entry into the environment.
- Models of environmental transport and material balances.

3.2.2 Data Categories

As an overview of the general data requirements for ranking hazards there are five categories to be considered. These are:

- Substance Identification
- Exposure
- Epidemiology (populations-at risk)
- Biological Effects
- Environmental Effects

Substance identification includes basic identification data, chemical and physical properties, composition data, compound impurities and chemical analysis techniques. There is also a need to know the specific activity of the wastes, the characteristics of the ionizing radiation being emitted, and the isotope.

Basic identification data permit unique definition of a substance and are essential for record-keeping and data storage/access. The chemical information required includes molecular formula, chemical structure, CAS registry number, CAS-preferred name, IUPAC-number, IUPAC-name, and other synonyms.

Chemical and physical property data provide preliminary indications of a substance's passage through the environment and the media where it is likely to accumulate, its potential for human uptake, its reactivity, and potential for degradation.

Exposure information includes data on occupational, environmental, and consumer exposures and attempts to define populations or systems at risk. These may be defined by monitoring data from the disposal site or may be estimates based on algorithms such as those developed by Stanford Research Institute and used by the U.S. National Cancer Institute (Dehn and Helms, 1974). The exposure data should take into account possible exposures from a variety of sources and media.

Epidemiology data are concerned with identification of populations exposed to toxic substances and their resulting adverse toxic reactions. These studies generally deal with an occupational group or with an identified section of the general population. For the purposes of the hazard assessments, the prevalence and incidence ratios are most significant.

Biological effects information, related to the chemical and radioactive properties of a compound, is required for identifying risks associated with a compound's acute and chronic toxicity, its target organs, and its metabolism. The toxicity data are generally from clinical observations, reports of adverse reactions, and animal toxicology studies.

Environmental effects information is often derived from a variety of sources including monitoring programs, laboratory experiments, and model simulations. When appropriate, the following areas should be included: biotic and abiotic accumulation, degradation, environmental transport and fate, and ecological toxicity. All relevant media should be considered and there should be a material balance on the environmental systems involved. Similarly, the evaluation of environmental effects should take into account a hierarchy of trophic levels from bacteria to vertebrates and higher plants.

3.3 Identifying Significant Substances

A summary table of the types of compounds which may be found in low-level waste burial sites is presented as Table 3-2. The chemical composition of low-level radioactive waste originating from the nuclear fuel cycle is reasonably well known and, compared to wastes not originating from the fuel cycle, consists of a relatively limited number of products. By comparison, low-level wastes not originating from the fuel cycle comprise an extremely large number of diverse chemical products. To reduce this list of potential burial site constituents to a more manageable size, the substances reported by Colombo, Weiss, and Francis (1977) from trench water analyses at Maxey Flats, Kentucky disposal site will be used as a basis for discussion of insert

TABLE 3-2. SUMMARY CHARACTERIZATION OF CHEMICALS IN LOW-LEVEL WASTES

Descriptive Class	Examples	Fuel Cycle	Other Sources
Agricultural Compounds	DDT, malathion, [^{14}C, ^{32}P, ^{35}S]		X
Alochols	methanol, cyclohexanol, diacetone		X
Aldehydes and Acetals	paraldehyde, 1, 1,-diethoxyethane		X
Aliphatic Halogenated Hydrocarbons	1,1,1-trichloroethane		X
Alkanes	cyclohexane		X
Alkenes	2,3-dimethyl-2-hexene		X
Alkyl Halides	1-isobutyl-4-ethyloctyl bromide		
Amino Acids	alanine, tryptohan [^{3}H, ^{14}C, ^{35}S]		X
Amino Sugars			X
Ammonia and Ammonium Salts	ammonia, ammonium sulfate	X	
Aromatic Hydrocarbons	benzene, toluene, p-xylene, anthracenes, dibenz a,h anthracene, [^{14}C]		X
Asphalt	natural or petroleum-derived	X	
Carboxylic Acids	citric acid, tartaric acid oxalic acid, hydroxy-acetic acid	X	X
Chelating Agents	ethylenediaminetetraacetic acid (EDTA) diethylenetriaminepentaacetic acid (DTPA) nietilotriacetic acid (NTA) triethylenetetraaminehexaacettic acid (TTHA)		Both FC and Non-FC
Carbohydrates	2-deoxy-d-glucose, [^{3}H, ^{14}C]		X
Drugs	acetylsalicyclic acid, actinomycin D, [^{14}C; ^{35}S]		X

TABLE 3-2. SUMMARY CHARACTERIZATION OF CHEMICALS IN LOW-LEVEL WASTES (cont.)

Descriptive Class	Examples	Fuel Cycle	Nonfuel Cycle
Esters			
Acetates	ethyl acetate		X
Adipates	dioctyl adipate, bis-2-ethylhexyl adipate		X
Biocarbons	natural or metabolic products of organisms		X
Borates	sodium teraborate, metaborate, boric acid, borate polymers	X	
Heptonates	stannous glucoheptonate		X
Phosphates	chromic phosphate, tributyl phosphate, sodium phosphate stannous polyphosphate, orthophosphates, ^{32}P)		X
Phthalates	di-2-ethylhexyl phthalate, diethyl, dibutyl, dioctyl phthalates	X	X
Sulfates	ammonium sulfates, calcium sulfate, sodium sulfate, other sulfate salts, ^{35}S	X	X
Ethers	bis(2-chloroethyl) ether, tetrahydrofuran, 1,4-dioxane		X
Fatty Acids	linoleic acid, oleic acid, oxalic acid, palmitic acid, [^{3}H, ^{14}C]		X
Hormones	histimine dihydrochloride		X
Inorganic Acids	boric acid, phosphoric acid, sulfuric acid, [^{32}P]	X	X
Ketones	methyl isobutyl ketone, d-fenchone		X

TABLE 3-2. SUMMARY CHARACTERIZATION OF CHEMICALS IN LOW-LEVEL WASTES (cont.)

Descriptive Class	Examples	Fuel Cycle	Nonfuel Cycle
Lipid-related Products	actylcholine chloride, sphingo-myeline [^{3}H, ^{14}C]		X
Miscellaneous Inorganic	calcium flouride, chloride, copper diatomaceous earth, fluoride, portlane cement, Mg, Zn, sodium hydroxide, sodium iodide	X	X
Nitrosamines	N,N-dimethylnitrosamine		X
Nucleosides			X
Nucleotides	adenosine-3',5'-cyclic phosphate [^{3}H, ^{14}C, ^{32}P, ^{125}I]		X
Nucleotide Sugars	guanosine diphospho-1-fucose, [^{14}C]		X
Organic Acids	acetic acid, benzoic acid, iodoacetic acid, phenylhexanoic acid		X
Peptides	---		X
Phenol and Phenolic Compounds	cresols, p-tert-butyl phenol		X
Prostaglandins [^{3}H, ^{14}C]	Prostaglandin E_2		X
Proteins	---		X
Protein-Labelling Reagents	acetic amhydride, 1-fluoro-2,4-dinitrobenzene, phenylisothiocycanate, [^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{125}I, ^{131}I]		X

TABLE 3-2. SUMMARY CHARACTERIZATION OF CHEMICALS IN LOW-LEVEL WASTES (cont.)

Descriptive Class	Examples	Fuel Cycle	Other Sources
Purines	adenine, guanine sulfate (^{3}H, ^{14}C)		X
Pyrimidines	uracil (^{3}H, ^{14}C)		X
Radionuclides	Ba-137m, 139, 140	X	
	C-14		X
	Ce-144	X	
	Co-58, 60	X	
	Cs-134, 136, 137, 138	X	
	Cr-51	X	
	H-3		X
	I-125, 131		X
	I-129	X	
	I-313, 132, 133, 134, 135	X	
	Fe-55, 59	X	
	La-140	X	
	Mn-54	X	
	Mo-99	X	
	Na-59		X
	P-32		X
	Pu	X	
	Rb-88		X
	Sr-89, 90, 91, 92	X	
	S-35		X
	Tc-99		X
	Th	X	
	U-naturals and daughters	X	
	Y-90, 91	X	
	Zr-95	X	
Resins	ion-exchange, urea		X
	formaldehyde	X	
Steroids	aldosterone, estradiol,		X
	progesterene		X
Vitamins	nicotinamide		X

potential adverse effects from toxic chemical wastes. The compounds identified by these analyses are listed by class in Table 3-2. A list of low-level wastes originating from the nuclear fuel cycle is provided in Table 3-3. These low-level fuel-cycle wastes include substances used as solidifying agents, compounds used as cleansing agents or absorbents, and elemental species from the fuel cycle.

3.3.1 Literature Search Procedures

Literature searches, encompassing chemical nomenclature, physical and chemical properties, analytical methods, biological effects of exposure and major environmental impacts, were performed for representative compounds listed in Table 3-2. Online computerized data bases and a core collection of toxicology and chemical reference manuals were used. These literature searching and evaluation techniques are described in greater detail in Volume II. The first stage of literature searching began with the identification of chemical synonyms for each compound to be applied when searching in appropriate data bases. Chemical nomenclature was obtained through the National Library of Medicine's online chemical dictionary (CHEMLINE). A core collection (also described in Volume II) of standard toxicology and chemical handbooks was then searched in an effort to compile additional synonyms, background information, physical and chemical properties, analytical methods, and summaries of known biological effects of the compounds.

3.3.2 Monographs and Bibliographies

The substances identified by Columbo, Weiss, and Francis (1977) were categorized by class--alcohols, alkenes, alkyl halides, aromatic hydrocarbons, aldehydes and acetals, aliphatic halogenated and nonhalogenated hydrocarbons, esters, ethers, phenol and phenolic compounds, and organic acids (Table 3-2). Each monograph summarizes the pertinent physical and chemical properties, information on use and occurrence, analytical methods and toxicity data for a specific compound. Monographs representative of each class of compound are presented in Volume II.

In addition to the monographs, extensive bibliographies covering physical/chemical properties and biologic activities were prepared on each of the compounds searched. These bibliographies are included as Volume III.

TABLE 3-3. CHEMICAL CONSTITUENTS IDENTIFIED IN FUEL CYCLE LOW-LEVEL WASTE

Orgainic Compounds

asphalt (solidification agents)
urea-formaldehyde resins
    (may contain alkali metal bisulfates)
carboxylic acids (decontaminating chemicals)
chelating agents
    (NTA, EDTA, DTPA, TTHA)

ion exchange resins
    (sulfonated and aminated organic polymers; modified polystrenes, copolymers of divinyl benzene and styrene are typical substrates)
phthalates
    (for filter testing)
vinyl ester styrene

Inorganic Compounds

ammonia
ammonium sulfate
boric acid
calcium fluoride
calcium sulfate
sodium tetraborate, metaborate
portland cement
    (with or without bentonite or vermiculite)
diatomaceous earth

Elemental Species

barium - 137m, 139, 140
bromine - 84
cerium - 144
cesium - 134, 136, 137, 138
chloride (Cl^-)
chromium - 51
    oxide or hydrated oxide
cobalt - 58, 60
    oxide or hydrated oxide
copper
fluoride
F^-, metallic fluorides
iodine - 129, 131, 132, 133, 134, 135
iron - 55, 59
    oxide or hydrated oxide
lanthanum - 140
magnesium
manganese - 54
    oxide or hydrated oxide
molybdenum - 99
niobium - 95
Pu
rubidium - 103, 106
strontium - 89, 90, 91, 92
uranium
    natural U and daughters
Tellurium - 132, 134
Th
Tritium
Yttrium - 90, 91
zinc
zirconium - 95
    oxide or hydrated oxide

3.4 Chemical Toxicity of Wastes Originating from Sources Other Than The Nuclear Fuel Cycle

A variety of organic substances have been identified in the trench waters at Maxey Flats, Kentucky. The compounds have been classified by functional groups such as alcohols, aromatic hydrocarbons, aldehydes, acetals, aliphatic halogenated hydrocarbons, ethers, esters, ketones, phenol and phenolics, and organic acids, and are listed in Table 2-11. Estimated concentrations for some of these compounds are indicated in Table 3-4. These concentrations do not represent a significant toxicological risk, and no acute or chronic adverse effects would be expected at the indicated concentrations. Compounds with a SAX hazard rating of 3 are listed in Table 3-5, and types and pathways for potential toxic effects are indicated. Such effects are usually produced by excessive exposures at concentrations substantially higher than those measured in trench waters at Maxey Flats. While compounds with suspect carinogenic, mutagenic, or teratogenic activity are listed in Table 3-6, there is insufficient information to estimate any risks associated with these compounds.

3.4.1 General Discussion

Detailed chemical monographs were prepared for at least one compound in each of the nine groups of chemicals identified by BNL at the Maxey Flats, Kentucky disposal site. The physical and chemical properties of nine representative compounds are summarized in Table 3-7, and pertinent toxicologic data are summarized in Table 3-8.

Among the compounds for which detailed literature searches were conducted and bibliographies prepared, 47 substances were identified which meet the following criteria:

- Appears on the Toxic Substances Control Act (TSCA) Interagency list of 300.

- Does not occur naturally (oxalic acid is an exception as it occurs naturally and is included on the TSCA Interagency List).

- Has been quantified in trench waters at Maxey Flats burial site (concentration in trench waters were approximated by Colombo, Weiss, and Francis, 1977).

TABLE 3-4. ESTIMATED CONCENTRATIONS OF SOME COMPOUNDS IDENTIFIED AT MAXEY FLATS[1]

Compound	Estimated Concentration (mg/L)
Benzoic acid	1.9
4-tert-Butyl phenol	0.05
bis(2-Chloroethoxy)methane	0.48
p-Cresol	2.60
Cyclohexanol	0.24
Diethyl phthalate	0.08
Hexanoic acid	4.7
2-Methylbutanoic acid	12.7
Naphthalene[2]	0.28
	0.30
Pentanoic acid	4.7
Phenylacetic acid	3.4
Phenylpropionic acid	9.8
α-Terpineol[2]	0.31
	0.49
Toluene[2]	3.50
	6.90
Tributyl phosphate[2]	0.29
	0.36
p-xylene	0.48

[1]From Colombo, Weiss, and Francis, 1977.
[2]Concentrations estimated from more than one trench.

TABLE 3-5. COMPOUNDS IDENTIFIED AT MAXEY FLATS WITH A SAX HAZARD RATING OF 3[1]

Compound	Type and Route of Toxic Effects With A Hazard Rating of 3			
	Acute Local	Acute Systemic	Chronic Level	Chronic Systemic
Acetic acid	irritant ingestion	---	---	---
bis(2-Chloroethyl)ether	irritant inhalation	ingestion inhalation skin absorption	---	---
1,4-Dioxane	---	ingestion inhalation	---	ingestion inhalation
Formic acid	---	ingestion	---	---
Hexanoic acid	irritant	---	---	---
Methyl isobutyl ketone	---	ingestion inhalation	---	---
Oxalic acid	irritant ingestion inhalation	ingestion inhalation	irritant ingestion inhalation	---
Tetrahydrofuran	irritant ingestion inhalation	---	---	---

[1] Sax, 1975

TABLE 3-6. COMPOUNDS WITH SUSPECT ACTIVITY IDENTIFIED IN TRENCH WATERS AT MAXEY FLATS[1]

COMPOUND	SUSPECTED Carcinogen	SUSPECTED Mutagen	SUSPECTED Teratogen
Phthalates			
Diethylhexyl phthalate			X
Di-2-ethylhexyl phthalate		X	X
Dioctyl phthalate			X
Dibutyl phthalate			X
Diethyl phthalate	X		X
Adipates			
Di-2-ethylhexyl adipate	X	X	
Diethyl adipate		X	
Phosphate			
Triethyl phosphate		X	
Tributyl phosphate			X
Miscellaneous			
1,4-Dioxane	X		
Hydroxyurea	X		
2-Methyl-1-butanol[2]	X		
1,1,2-Tricholoroethane[2]	X		
bis-2-Chloroethyl ether	X		
Naphthalene	X		
Biphenyl	X		
o-,m-, and p-Cresol	X		
Phenol	X		
Naturally Occurring			
1-Leucine			X

[1]Colombo, Weiss, and Francis, 1977
[2]Isomers of compounds identified

TABLE 3-7 Summary of Physical/Chemical Properties of Selected Compounds

Compound	Physical State at STP	MP (°C)	BP (°C)	Water Solubility	Other Solubility	P (Alcohol/Water)	VP (at 25°C)	Specific Gravity (d_4^{20})	pH	Stability	Reactivity
Cresols										o-cresol is very reactive towards most radicals; is degraded by HO and O_3 in air and by organic radicals in water	can be oxidized by oxidizing agents; under acidic conditions cresols are readily alkylated by alkylhalides or alkenes can form esters with weak acids
o-cresol	liquid	30.8	190.8	2.9 g/100g (46.2°C)		89.13	0.2453	1.0470			
m-cresol	liquid	10.9	202.8	2.7 g/100g (50.8°C)		91.2 to 102.3	0.1528	1.0340			
p-cresol	liquid	35.5	201.8	2.21 g/100g (30°C)		87.10	0.1080	1.0341			
diacetone alcohol	liquid	-44	167.9	miscible	alcohol, ether, other solvents		1.1 (20°C)	0.9306 ($_4^{25}$)			major transformation product is acetone
1,1-di-ethoxy-ethane	liquid	-100	102.7	5 g/100 center ml	alcohol, ether, heptane, methylcyclohexanol, alcohols, ether acetate	0.51, 1.17 (calculated)	10 (8°C)	0.8054			hydrolyses to hemiacetal or acetaldehyde plus ethyl alcohol
di-2-ethyl-hexyl phthalate	liquid	-50	-	0.005 g/100 ml (25°C)	mineral oil	3876.58 (calculated)	< 0.01 (25°C)	0.9861 (d_{20}^{20})			is converted to derivatives of mono (2-ethyl-hexyl)phthalate, 2-ethyl-hexanol
1,4 dioxane	liquid	12	101	soluble	organic solvents, aromatic hydrocarbons, oils	0.38	37.0	1.0329		stable to light	reacts with O_2 to form explosive peroxides (especially in presence of moisture)
1-octanol	liquid	-16 to -17	194 to 195	insoluble	alcohol, chloroform, ether	1412.5		0.827			
oxalic acid	crystals	189	at ∿ 101-102	1 g/∿ 7 ml	alcohol, ether, glycerol; insoluble in benzene, chloroform, petroleum ether	0.15-0.37 (calculated)		1.0035 ($d_4^{17.5}$ aq. solu.)	1.3 (0.1M solu.)		forms soluble salts of alkali metal ions (Li, Na, K, Ca) and with ferous salts.
tolune	liquid	-95	110.4	slightly soluble	alcohol, chloroform, ether, acetone, glacial acetic acid, carbon disulfide		36.7 (30°C)	0.866			
1,1,1-trichloro-ethane	liquid	-32.62	74	insoluble	alcohol, ether, acetone, benzene, carbon tetra-chloride, methanol, most organic solvents	93.9073 (calculated)		1.3376		inert to atmospheric oxidation under normal conditions	hydrolyses in excess of free water, producing HCl, acetic acid, phosgene, vinylidene cholride; decomposes under UV light to HCl, phosgene, dichloroacetylene

MP = melting point; BP = boiling point; P = partition coefficient; VP = vapor pressure

TABLE 3-8 SUMMARY OF BIOLOGICAL ACTIVITY OF SELECTED COMPOUNDS

Substance	Acute LD_{50} oral (mg/kg)	Acute LD_{50} inhalation	Acute LD_{50} Dermal (mg/kg)	Skin irritation	Eye irritation	Metabolites	Route of excretion	Carcinogenic	Mutagenic	Teratogenic	Neurotoxic	Target Organs	OSHA Standard	Hazard Rating[1]
cresol	121 (ortho) 242 (meta) 207 (para) (rat)	NA	1380 (ortho) 2050 (meta) 301 (para) (rabbit)	P	P	cresol, ethereal sulfates, ether glucuronides	urine	P (promoter)	NT	NT	P	CNS, liver, kidney, lung pancreas spleen	5 ppm	3
diacetone alcohol	4000 (rat)	100 ppm (TCLo-human)	NA	P	P	NT	NT	NT	NT	NT	CNS, depression	CNS liver, kidney	50 ppm	2
1,1-diethoxy ethane	4600 (rat)	>4000 ppm (rabbit)	10,000 (rabbit)	P	P	possibly a hemiacetal, acetaldehyde, or ethyl alcohol	NT	NT	NT	NT	NT	CNS (?)	NA	2
di(2-ethylhexyl)phthalate	31,000 (rat)	NA	25,000 (rabbit)	N	NA	monoester derivatives, 2-ethylhexanol	urine	N	P	P	NT	low toxicity	5 mg/m^3	2
1,4 dioxane	5170-7120 (rat)	51.3 mg/L/ 4 hrs. (rat)	7,600 (rabbit)	P	P	β-hydroxyethoxyacetic acid, 1,4-dioxane	urine	P	NT	NT	NT	liver, kidney	10 ppm	3
1-octanol	1790 (mouse)	NA	NA	P	P	aldehyde, acid	NT	NT	NT	NT	CNS depression	CNS	NA	NA
oxalic acid	71 μg/kg (LDLo)	NA	112 (LDLo-cat, s.c.)	P	P	calcium oxalate	urine	NT	NT	NT	NT	kidney	1 mg/m^3	3
toluene	500 (rat)	25 mg/L (mouse)	14,000 (rabbit)	P	P	hippuric acid, toluene	urine; exhaled unchanged	NT	NA	NT	CNS depression	CNS hematopoietic	220 ppm	2
1,1,1-trichlorothane	14,300 (rat)	1000 ppm (LcLo rat)	550 (LDLo-rabbit, s.c.)	P	P,N	trichloroethane, trichloroethanol, trichloroacetic acid	exhaled unchanged	N	NT	N	CNS depression	CNS liver kidney cardiovascular	350 ppm	2

Key

N = negative, based on available data
P = positive, based on available data
NT= not tested
NA= not available

LD_{50} = lethal dose, 50%
LDLo = lowest published lethel dose
TCLo = lowest published toxic concentration
s.c. = subcutaneous administration
CNS = central nervous system

Footnotes

[1] Highest rating assigned by Sax (1975) to any type or route of exposure

The TSCA list of 300 represents an assessment of hazard priorities and significance of these chemicals and provides a reasonable basis for discussion of specific toxic chemicals identified in shallow land burial sites. While there is a paucity of quantative information on the amounts and distribution of these substances at the site, it is possible to rank these substances by industrial, economic, and potential adverse effects factors. In developing the TSCA list of 300, the Interagency Committee based its criteria on four factors: production quantity, occupational exposure, general human exposure, and environmental exposure. The selection process further eliminated those chemicals which are: (1) currently under or being considered for regulation; (2) reasonably characterized as non-hazardous; (3) considered essentially inert materials; or (4) naturally occurring products which would be difficult to characterize for evaluation purposes.

According to the licensing requirements for low-level waste burial at Maxey Flats, Kentucky, the Barnwell facility in South Carolina, and the Beatty facility in Nevada, the disposal of radioactive waste is not authorized under those licenses when the hazard of any chemically toxic waste associated with the radioactive waste exceeds the radiological hazard. Any chemically toxic waste listed in Category 3 of the manual Dangerous Properties of Industrial Materials, by Irving Sax (Sax, 1975) shall be considered more hazardous than its associated radioactive material until the responsible agency, for example the Kentucky Department of Human Resources, has been supplied with sufficient information to determine that the radiotoxicity exceeds the chemical toxicity. Table 3-5 lists the compounds identified in Maxey Flats trench waters which have a hazard rating of 3 as defined by Sax (may cause death or permanent injury after very short exposure to small quantities).

As a result of the literature searches on the compounds identified in trench waters, it is of interest that acute rat oral LD_{50} values vary from <200 mg/kg for the cresols to $>26,000$ mg/kg for di-(2-ethylhexyl) phthalate. In addition, several suspected or known carcinogens, mutagens, and teratogens have been identified (Table 3-7). Other compounds present, such as phenol, toluene, biphenyl, hydroxyurea, benzoic acid, methyl isobutyl ketone and the phthalate plasticizers, are potential neurotoxins.

Various radionuclides are also found in wastes originating from hospitals, universities, biological research centers, and industry other than the nuclear fuel cycle, and there has been

a steady increase in the use of radionuclides over the past few years (Anderson _et al._, 1978). However, the only nuclide which would be expected in measurable quantities after several months would be carbon-14 and tritium.

Although it has not been possible to clearly define the total spectrum of low-level wastes, it is possible to surmise that many potentially toxic substances of widespread research interest, such as the aflatoxins and sterigmatocystin may well be present in the disposal sites. These substances are potent liver toxins produced by microorganisms and have been identified in various food crops. They have also been shown to increase the field of tumors in animal experiments and have created considerable research interest. These, and other substances, would be expected to be discarded with scintillation fluids and/or animal carcasses.

3.4.2 Biological Effects of Selected Substances

The potential human health and environmental hazards for representative organic compounds on which monographs have been prepared are summarized below. These summaries are based on the toxicologic information obtained as a result of extensive literature searches.

Cresols (ortho, meta, and para). The cresols are classified as cytoplasmic poisons, affecting the entire organism, particularly the central nervous system (CNS), liver, and kidney. The lungs, pancreas, and spleen may also be injured. Cresols are strong irritants, producing burns of the skin and eyes on direct contact with concentrated solutions. Effects in humans following long-term exposures have not been reported; however, irritation, CNS excitability, and protein denaturation have been observed in laboratory animals as a result of repeated inhalation exposures (NIOSH, 1978).

The most probable route of exposure is absorption through the skin, although cresols also may be absorbed through the mucous membranes of the gastrointestinal and respiratory tracts. Because of their low vapor pressure and disagreeable odor, cresols usually do not present an acute inhalation hazard (Deichmann and Keplinger, 1963; Gordon, 1976).

All three isomers of cresol in tobacco smoke have been determined to be active tumor promoting agents (Gordon, 1976). In addition, Zamfir (1972) reported that all three isomers demonstrate significant carcinogenicity. The above information shows the need for further evaluation of the

genetic activity of the cresols. Investigations concerning mutagenic or teratogenic potential of cresols have not been reported in the literature.

In addition to demonstrated human and animal toxicity, cresols have produced adverse effects among plants and microorganisms. With regard to plants, cresols are herbicides but, in some plants, function as dormancy-breaking agents or as selective antineoplastic agents. Although cresols are metabolized by some yeasts and occur as metabolic byproducts of some fungi, they are toxic to most microorganisms (Gordon, 1976).

Diacetone Alcohol. Diacetone alcohol has not been tested for potential mutagenic, teratogenic, or carcinogenic effects. Liver injury following lethal and sublethal doses, respiratory irritation, eye irritation, and transient corneal damage have been observed among experimental animals. An acute oral LD_{50} of 4000 mg/kg (rat), an acute dermal LD_{50} of 14.5 mg/kg (rabbit), and an acute intramuscular minimum lethal dose of 3-4 ml/kg (rabbit) have been reported (Smyth and Carpenter, 1948; Rowe and Wolf, 1963). Narcotic effects, restlessness, excitement, somnolence, and marked depression of respiration, leading to respiratory failure and death, have also been observed (Walton, Kehr, and Lovenhart, 1928).

Eye, nose, and throat irritation, pulmonary discomfort, and the possibility of dermatitis (following frequently repeated or prolonged contact) have been reported among humans exposed to diacetone alcohol (Shell Chemical Corp., 1957; Silverman, Schulte, and First, 1946). In a review of the toxicologic properties of diacetone alcohol, Rowe and Wolf (1963) state that the substance is not highly irritating to the skin, and that its warning properties (irritation) preclude most possibilities of overexposure and, consequently, serious injury.

1,1-Diethoxyethane. Little information is available concerning the toxicologic properties of 1,1-diethoxyethane. An acute oral LD_{50} in rats of 4600 mg/kg and an acute intraperitoned LD_{50}, again in rats, of 900 mg/kg has been reported (Fassett, 1963). 1,1-Diethoxyethane has produced narcosis and slight eye irritation. It is metabolized possibly to a hemiacetal, acetaldehyde, or ethyl alcohol (Fassett, 1963).

1,1-Diethoxyethane has the tendency to polymerize on standing, indicating the compound is unstable in its monomeric form. This, coupled with its low octanol/water partition

coefficient, makes it highly unlikely that the compound will persist in the environment.

<u>Di(2-ethylhexyl)phthalate</u>. Di(2-ethylhexyl)phthalate (DEHP) has generally been considered to be of low acute toxicity based primarily on its large acute LD_{50} values. The compound is metabolized and excreted fairly rapidly in laboratory animals. It appears that DEHP is teratogenic (Singh, Lawrence, and Autian, 1972) and possibly mutagenic (Singh, Lawrence, and Autian, 1974); however, further testing is needed to confirm these findings. Positive evidence of carcinogenic or cocarcinogenic effects has not been found in the literature.

Biochemical activity such as inhibition of lipid biosynthesis, a reduction in serum cholesterol and triglyceride concentrations, and effects on hepatic mitochondrial enzymes and mixed function oxidase parameters have been observed in animals (Reddy <u>et al</u>., 1976; Bell, 1976; Bell <u>et al</u>., 1978; Lake <u>et al</u>., 1976). The significance of this observation in terms of human exposure needs further evaluation.

In 1976, 314 million pounds of DEHP were produced in the United States. As of 1972, no restrictions had been placed on phthalates with regard to industrial wastes. Loss of DEHP to the environment during manufacturing and processing may be large, simply due to the volume of the compound produced. In considering the widespread distribution, use, and disposal of some products containing phthalates - especially plastic, such as PVC, in which DEHP may constitute as much as 40% of the final product - there is a need to evaluate the potential for releases to air, water, and terrestrial systems.

DEHP was demonstrated by Metcalf <u>et al</u>. (1973) to be a microchemical pollutant which is rapidly biomagnified by a variety of aquatic plants and animals. DEHP biodegraded very slowly in algae, <u>Daphnia</u>, mosquito larvae, snails and clams, and, more rapidly, in fish by hydrolysis at the ester bonds to form monoethylhexyl phthalate, phthalic acid, phthalic anhydride, and a variety of polar metabolites and conjugates. DEHP and DDT closely resemble each other with respect to the rate of uptake and storage in the intermediate trophic levels. However, DEHP is metabolized fairly rapidly in fish and mammals, thus, the largest concentration of DEHP would be expected at intermediate points, rather than at the top of the food chain as occurs with DDT.

At low chronic concentrations, the data indicate that DEHP can be detrimental to the reproduction of aquatic organisms (Mayer and Sanders, 1973).

<u>1,4-Dioxane</u>. 1,4-Dioxane is fairly rapidly metabolized and excreted in laboratory animals and humans (Young *et al*., 1976a, Young *et al*., 1976b; Braun and Young, 1977). It has been postulated that toxic effects are manifested only when the metabolic pathway for 1,4-dioxane becomes saturated (Young *et al*., 1976a; Young and Gehring, 1975). Degenerative liver and kidney changes have been observed in experimental animals following exposure via oral, inhalation, parenteral and dermal routes (de Navasquez, 1935; Fairley, Linton, and Ford-Moore, 1934; Argus *et al*., 1973).

Several cases of acute illness and death have been reported among workers occupationally exposed to 1,4-dioxane. Kidney and liver necrosis and edematous conditions in the lungs and brain were reported in most cases. (Barber, 1974; Johnston, 1959). Eye, nose, and throat irritation have been reported following brief (15-minute) experimental human exposures via inhalation to 1,4-dioxane concentrations exceeding 200 ppm (Silverman, Schulte, and First, 1946).

Several experiments have shown 1,4-dioxane to be carcinogenic in experimental animals following dermal and oral administration, but not following inhalation exposure (Argus, *et al*., 1973; Argus Arcos, and Hoch-Ligeti, 1965; Hoch-Ligeti, Argus, and Arcos, 1970; King, Shefner and Bates, 1973; Kociba *et al*., 1974; Torkelson *et al*., 1974). No reports have been published concerning the possible carcinogenicty of 1,4-dioxane in man. 1,4-Dioxane has produced effects *in vitro* similar to those of thalidomide (Franceschini, 1964; Salzgeber and Salaun, 1965); however, the significance of these findings, with regard to potential teratogenic activity, is not clear at present.

Although 1,4-dioxane is a highly toxic material in animals at high concentration and in humans occupationally overexposed, it is rapidly metabolized by mammalian systems and possesses very low lipophilicity. This tendency not to accumulate in biological systems suggests that 1,4-dioxane will not persist in a food chain, and will not endanger predatory species toward the top of the food chain. In addition, it is highly probable that 1,4-dioxane has a low residence time in the environment due to its liability to biodegradation.

<u>1-Octanol</u>. The toxicity of primary aliphatic alcohols increases with increasing chain length up to a point, and

narcotic potency may increase even faster than lethality. Normal Octanol is, therefore, thought to be moderately toxic with the probable oral lethal dose in humans between 0.5 and 5 g/kg, but may cause hemolysis once ingested since it is a hemolytic agent in vitro. 1-Octanol is a central nervous system depressant and may cause headache, muscle weakness, respiratory failure, vertigo and coma in toxic doses. It may also be a myocardium depressant. Most liquid alcohols are primary skin irritants and vapors may irritate eyes, nose, and throat. 1-Octanol can be oxidized rather rapidly to its corresponding aldehyde or acid and significant metabolic acidosis may occur (Gosselin et al., 1976).

Biochemical alterations indicated by a decrease in ATPase activity may occur from administration of 1-octanol (Mitjavila, Lacombe, and Carrera, 1976; Koch, 1972); the significance of these findings requires further study.

Effects of exposure to 1-octanol among humans have not been found in recent literature reports.

1-Octanol is in widespread use as a solvent and as a flavoring and cosmetic additive. The compound may be widely distributed in the environment as a result of its numerous applications. The large partition coefficient of octanol indicates a high potential for biomagnification. High accumulation rates will probably occur in the lower trophic levels rather than at the top of the food chain since rapid metabolism of octanol occurs in mammalian systems.

An aquatic toxicity rating for 1-octanol has been reported: TLm96: 100-10 ppm (Fairchild, 1977). 1-Octanol, on the basis of this rating, is considered to be slightly toxic to aquatic organisms. The aquatic toxicity rating does not take into account chronic or sublethal effects, however, which may ultimately be of more important ecological significance.

Oxalic Acid. Acute exposure to large dosages of oxalic acid may cause severe local effects (burning and irritation of the skin, eyes, and mucous membranes of the respiratory tract) and systemic effects (hypocalcemia, convulsions, cardiovascular collapse, and renal damage) (Fassett, 1963; Littledike, James, and Cook, 1976). Little information regarding chronic, low-level exposure to oxalic acid is available. Oxalic acid occurs naturally in a number of common foodstuffs consumed by humans. Figures concerning the average dose or daily intake of oxalic acid from such foodstuffs are not available. A 70-day feeding study in rats revealed marked depression in growth rates and histopathological changes in gonadal tissues

(Goldman, Doering, and Nelson, 1977). The applicability of this study to possible results of human exposure to oxalic acid cannot be estimated since the authors failed to demonstrate whether some of the observed effects were due directly to oxalic acid exposures or were due to the altered nutritional states (abnormal body and organ weights) which resulted during oxalic acid exposure.

An aquatic toxicity rating for oxalic acid has been reported: TLm 96: 1000-100 ppm (Fairchild, 1977). Based on this rating, oxalic acid presents a very slight toxicity to aquatic organisms. However, the aquatic toxicity rating does not take into account chronic or sublethal effects which may be of ecological importance.

Toluene. The most probable route of exposure to humans results from inhalation. However, toluene is absorbed slowly through the skin and has also been demonstrated to be irritating to the skin. The low solubility of toluene in blood and water indicates that the circulating blood rapidly comes to equilbrium with toluene vapor in the alveolar air. Part of the absorbed toluene is eliminated in the exhaled breath, however, a large percentage is oxidized to benzoic acid, conjugated with glycine, and excreted as hippuric acid in the urine. The presence of toluene in the blood may be used as an indicator of exposure if the exposure period has been sufficiently long enough to approach equilibrium (Gerarde, 1963).

Skin and eye irritation have been reported following exposure to toluene. Toluene is a powerful narcotic and acute exposures may result in mild fatigue, weakness, mental confusion, insomnia, dizziness, and nausea. Subjects may show loss of coordination and a staggering gait. Chronic exposures have been associated with harmful effects on hematopoietic tissue in females, "inappropriate" speech, brief episodes of memory loss, abnormalities in electroencephalograms, dermatitis, hepatorenal damage, and enlarged livers (Cieslinka et al., 1969; Von Oettingen et al., 1942; Satran and Dodson, 1963; Gerarde, 1960; O'Brien, Yeoman, and Hobby, 1971; Greenburg et al., 1942).

Toluene is metabolized by the fruits of several plants, is degraded by soil microbes, and volatilizes readily. It is toxic to insects, nematodes and methane-producing bacteria. It is reasonable to expect rapid removal of small amount of toluene from the soil. Toluene is moderately toxic to fish and has been found to be present in the muscle and liver of contaminated fish, including eels.

1,1,1-Trichloroethane. 1,1,1-Trichloroethane is generally believed to be a solvent of relatively low toxicity, absorbed through the gastrointestinal tract, lungs, and through the skin (Stahl, Fatteh, and Dominguez, 1969). Significant adverse effects following repeated exposure of human volunteers at 500 ppm have not been reported; and it has been stated that at concentrations below those sufficient to depress the respiratory center, the potential for permanent injury from 1,1,1-trichloroethane exposure is small (Stewart et al., 1969). Reports of fatal human exposures have indicated that most such incidents occur when 1,1,1-trichloroethane is used in small, enclosed areas with poor ventilation where high concentrations of vapor can rapidly accumulate.

An extensive review of the biological activity of 1,1,1-trichloroethane has been published by NIOSH (1976). Reports of human exposures are reviewed which describe central nervous system effects (anesthesia, loss of ability to stand, lightheadedness and impaired coordination), cardiovascular effects (lowered blood pressure, ECG changes, decreased peripheral resistance and cardiac insufficiency), liver and kidney effects (increased serum transaminase, elevated urinary urobilinogen and increased serum billirubin) and irritation of skin and mucous membranes.

Results of animal studies to date indicate that 1,1,1-trichloroethane does not possess teratogenic or carcinogenic properties in mice or rats. However, this is based upon limited testing and further studies are needed to confirm these findings.

1,1,1-Trichloroethane is insoluble in water and is inert to atmospheric oxidation under normal conditions but may be hydrolyzed in an excess of free water (AIHA, 1961; Walter et al., 1976). A relively high partition coefficient of 93.9074 has been calculated, based upon a solubility of 0.44 g/100 g water.

Observations of trichloroethane excretion following exposure of humans and laboratory animals (reviewed in NIOSH, 1976) indicate that the compound is, to a large extent, excreted unchanged in the expired air. Urinary excretion of 1,1,1-trichloroethane and several metabolites (trichloroethane and trichloacetic acid) has been reported from animal studies; and it is believed that aerobic and anaerobic microorganisms are unable to metabolize 1,1,1-trichloroethane (Walter et al., 1976). These findings suggest that environmental degradation

of tricholorethane will probably not be facilitated to any significant extent by microbial or mammalian metabolism.

3.5 Chemical Toxicity of Low-Level Wastes Originating from the Nuclear Fuel Cycle

A number of compounds have been identified as chemical constituents of low-level waste originating from the nuclear fuel cycle (Table 3-3). Chemical characterization of some fuel cycle low-level waste is unavailable at present; hence, the list of compounds presented in Table 3-3 is not inclusive. For discussion purposes, the identified waste constituents have been grouped into organics, inorganic compounds, and elemental species. The concentration of these waste constituents in air and water at the sites are predicted to be at levels which are not expected to produce acute effects. The chemical toxicity of individual constituents is briefly outlined below.

3.5.1 Organic Constituents

Urea-formaldehyde resins and ion exchange resins are the primary types of organic constituents of fuel cycle low-level wastes identified. Other organics include: detergents from laundry wastes and equipment, cleaning, chelating agents (EDTA, DPTA), and decontamination solutions (critic acid and proprietary decontamination products). Urea-formaldehyde resins may contain low concentrations of alkali metal bisulfates. Ion exchange resins are described as sulfonated and aminated organic polymers. Resin bases may consist of a styrene and divinyl copolymer. The polymeric resins may decompose to the respective monomers with prolonged exposure to air and sunlight. Decomposition by photochemical reaction would proceed slowly under a covering of dust; however, other constituents of low-level waste present in the trench, particularly acids, may affect some degree of decomposition. Potential health and environmental hazards would stem from the presence of styrene and benzene and their derivatives which may be derived from the decomposition of such polymers. Chelating agents have a strong affinity for actinide, rare earth, and transition metals. They are, therefore, used in decontamination solutions, in treating lead and plutonium poisoning, and in agriculture to increase the rate of uptake of mineral nutrients. Chelating agents have a low capacity to be ion exchanged in soils and in the absence of sunlight and under anaerobic conditions, as in a burial trench, are likely to persist. Chelating agents, therefore, could increase the migration potential of radionuclides in decontamination wastes and in the migration paths.

3.5.2 Inorganic Constituents

Ammonia. Ammonia can be produced by reduction of nitrates and nitrites in wastes, but no excessive concentrations of ammonia are expected at waste sites. Conjunctivitis and complaints of eye and respiratory irritation have occurred among some workers exposed to ammonia at concentrations as low as 20 ppm. Lacrimation, eye irritation, and irritation of the upper respiratory tract may occur during short exposures to ammonia at concentrations of 100 ppm or more. At higher concentrations (500 ppm), irregular minute ventilation, hyperpnea, increased blood pressure and pulse rate as well as lacrimation and upper tract respiratory irritation have been noted. Ammonia inhalation at high concentrations may be fatal, with death resulting from pulmonary edema (NIOSH, 1974).

Other sources of ammonia are ammonium sulfate found in decon solutions and sodium ammonium sulfate from chemical regeneration of ion exchange beds. Ammonium sulfate is a local irritant; its acute and chronic systemic effects are not known. Sodium ammonium sulfate is a compound of moderate toxicity. Lethal intravenous doses of 1220 and 4470 mg/kg in mice and guinea pigs respectively, are indicated in the NIOSH toxic substances list (Sax, 1975; Fairchild, 1977). Also, another source of ammonia could be from ammonium citrate found in decon solutions.

Boric Acid and Sodium Tetraborate. These boron compounds are used as chemical shims in PWR's. Excessive exposures can cause irritation of the eyes, nasal membranes, and respiratory tract. Systemic effects vary with the specific compound. Absorption through abraded or burned skin and ingestion of boric acid can result in gastrointestinal disturbances and erythematous rash, although dryness of the skin and mucous membranes and kidney injury have also been observed. Biochemical mechanisms of boron toxicity are incompletely understood but may include effects on the nervous system, enzyme activity, carbohydrate metabolism, hormone function and oxidation processes (Key *et al*., 1977).

Calcium Fluoride. Any fluoride present in the wastes, would be expected to react with calcium already present in the soil to form calcium fluoride. Any toxic effects from exposure to calcium fluoride are expected to be attributable to the fluoride component, calcium being relatively innocuous. Fluorides are discussed in Section 3.5.3 below.

Diatomaceous Earth. This material is primarily used as a filter media in liquid radwaste filtration systems. Long-term, inhalation exposure to diatomaceous earth at high concentrations may produce silicosis. Silicosis has been reported to develop rapidly, following as little as 2 months exposure, among industrial workers inhaling diatomaceous earth containing crystalline silica (International Labor Office, 1972).

3.5.3 Elemental Species

Barium. A benign pneumoconiosis may result from inhalation of the dust of barium sulfate. Soluble barium compounds markedly increase muscle contractibility and may cause gastroenteritis, muscular paralysis, and ventricular fibrillation when administered orally or by ingestion. Insoluble barium compounds, when taken orally, are not absorbed sufficiently to cause toxic effects (Casarett and Doull, 1975).

Cerium, Lanthanum, and Yttrium. Cerium and lanthanum are members of the lanthanide series. Yttrium is often included in this series because of its similarity to other members. Little is known of the inhalation toxicity of these elements, although orally they are of low toxicity and parenterally their acute toxicity is rather high. Members of this series may complex with proteins, stimulate the succinic dehydrogenase system or inhibit ATP activity. Intravenous injections in man have caused local thrombophlebitis. The lanthanons additionally have an anticoagulant action in blood when adiministered intraveneously. A variety of toxic side reactions may also occur, including headache, fever, chills, and muscle pain, abdominal cramps, hemoglobinemia and hemoglobinuria (Stokinger, 1963).

Cesium. Cesium is absorbed and bound in kidney and muscle cells following oral administration. It may replace potassium in some circumstances--an action that has the potential for causing adverse effects. Neuromuscular disturbances have been reported in animals following cesium administration (Casarett and Doull, 1975).

Chromium. Dermatitis, hepatic injury and lung cancer among industrial workers have been associated with occupational exposure to chromium compounds. Parenteral administration of chromic oxide has produced gastroenteritis, peripheral vascular collapse and toxic nephritis. Some studies have indicated that $Cr^{+}3$ as well as $Cr^{+}6$ produces toxic effects, while other investigators believe that $Cr^{+}6$ is the toxic species and that $Cr^{+}3$ along with elemental chromium are nontoxic (DiPalma, 1971).

Copper. Systemic effects resulting from exposure to copper salts have included liver and kidney damage, CNS stimulation followed by CNS depression, and capillary damage. Levels of copper required to produce chronic poisoning in man are thought to be about 10 times greater than the normal daily intake. Wilson's disease (hepatolenticular degeneration), resulting from an increase in absorption of normal amounts of ingested copper, is characterized by increased levels of copper in the tissues (DiPalma, 1971).

Fluorides. Some fluoride compounds are primary skin irritants and may produce thermal or chemical burns. Systemic effects may result from skin absorption following fluoride burns, and prolonged inhalation of dusts and vapors may result in an osteosclerosis. Acute toxicity from large ingested doses of fluoride compounds may include the gastrointestinal system and CNS involvement (Key et al., 1977).

Iron. Acute toxicity from excessive ingestion of iron preparations may be characterized by gastrointestinal irritation, followed by pneumonitis, convulsions, gastrointestinal bleeding, neurologic manifestations, signs of hepatic toxicity, and possibly, death. Hemosiderosis or hemochromatosis may result from chronic, excessive intake of iron. Long-term inhalation of iron oxide has been reported to cause a benign pneumoconiosis (Casarett and Doull, 1975).

Magnesium. Magnesium is one of the more important cations in the body. With the exception of metal fume fever resulting from inhalation of high concentrations of magnesium oxide fumes, industrial poisoning from magnesium exposure is not known. Acute poisoning has been reported in patients with severely reduced urinary excretion and has also occurred following prolonged retention of large doses of soluable magnesium compounds (given to patients in an attempt to produce catharsis) (DiPalma, 1971).

Manganese. Manganese also is an essential element, functioning as an enzyme cofactor in mitochondrial oxidative phosphorylation. Chronic industrial exposures to high concentrations of manganese-containing dusts have produced a neurologic syndrome and pneumonitis (DiPalma, 1971).

Molybdenum. Varying toxicities are observed with different molybdenum salts. Soluble, hexavalent molybdenum compounds are absorbed from the gastrointestinal tract. Urinary excretion accounts for at least half of the excretion of molybdenum. Experiments with guinea pigs have shown increased

bone levels of molybdenum following inhalation and increased liver and kidney levels following injection. Anemia, poor growth rates, and diarrhea have developed in cattle and sheep grazing in pastures with high molybdenum concentrations; and joint deformities have resulted from continued exposure (Casarett and Doull, 1975).

Rubidium. Rubidium appears to substitute successfully for potassium in many physiological processes. Evidence for adverse effects in man has not been reported. Hyperirritability, muscle spasms, convulsions and death of the young prior to weaning have been reported among animals administered an excess of rubidium in conjunction with a potassium-deficient diet (Casarett and Doull, 1975).

Strontium. Strontium and its compounds (excluding the radioisotope ^{90}Sr) are of relatively low toxicity. Respiratory failure following intravenous injection, inhibition of bone calcification, stunting of growth following ingestion and skeletal accumulation have been reported (Stokinger, 1963).

Uranium. Hexavalent uranium (in the form of UO_2^{++}) and other forms of uranium which can be easily oxidized to the hexavalent state present the major toxicological hazard. Uranium compounds which are soluble in body fluids are irritating to the skin and eyes and produce kidney damage which may result in acute renal necrosis and death. Uranium compounds which are not soluble in body fluids are considered to be relatively nontoxic.

Zinc. An essential element for normal growth and development, zinc is considered to be relatively nontoxic to mammals (DiPalma, 1971).

Zirconium. Sensitivity reactions and pulmonary changes may result from exposure to some of the soluble zirconium compounds. Insoluble compounds (i.e., ZrO_2) are considered to be physiologically inert (DiPalma, 1971).

4.0 BURIAL GROUND CHARACTERISTICS AND OPERATING PROCEDURES

4.1 Method of Study

A review of the literature detailing physical site characteristics, operating procedures and observed releases was conducted. This review included visits to the South Carolina Department of Health and Environmental Control office, the Chem-Nuclear Barnwell Facility, and the NRC Division of Waste Management at NRC headquarters for additional reference material. Sections 4.2 and 4.3 present the results of this review.

4.2 Shallow Land Burial Sites

The first commercial burial ground for "other than high level waste" opened at Beatty, Nevada in 1962, followed closely by activation of the burial site at Morehead, Kentucky. Prior to that time, disposal of these wastes was accomplished by two routes: dumping in the ocean at designated sites, and burial at Atomic Energy Commission (AEC) burial sites provided at government-operated facilities for disposal of government-generated radioactive wastes. Since 1963, the AEC and its successor agencies have not accepted waste from private industry. Beginning in 1963, the AEC took steps to discourage the use of sea disposal and by 1970 this practice was essentially completely terminated.

There have been six sites operated by three private companies. Table 4-1 locates these sites and gives other information concerning the operator and address for each.

TABLE 4-1

COMMERCIAL BURIAL SITES IN USA

West Valley	Nuclear Fuel Services, Inc.	Box 124 West Valley, NY 14171
Barnwell	Chem-Nuclear Systems	3101 Carlisle Street Box 6336 Columbia, SC 29206
Maxey Flats	Nuclear Engineering Co., Inc.	Box 146 Morehead, KY 40351
Sheffield	Nuclear Engineering Co., Inc.	Box 158 Sheffield, Il 61361
Beatty	Nuclear Engineering Co., Inc.	Box 578 Beatty, NV 89003
Richland	Nuclear Engineering Co., Inc.	Box 638 Richland, WA 99352

The West Valley site was voluntarily closed by Nuclear Fuel Services and receipt and burial suspended on March 11, 1975. The Sheffield site is at full licensed capacity and future expansion appears doubtful. In June 1976 the Kentucky State legislature imposed a $0.10/lb surtax on all radioactive waste buried at Maxey Flats following the determination that radionuclides may have migrated from the site. This action effectively shut down the site by making disposal there prohibitively expensive. In December 1977 the site was officially closed by the State of Kentucky

The three sites open at the present time, Beatty, Richland and Barnwell, have been subject to much controversy in recent months due to actions taken by the governors of Nevada, Washington and South Carolina. These actions are discussed in Section 1.0 of this report.

4.2.1 Licensing Requirements and Restrictions

The Nuclear Regulatory Commission (NRC) has responsibility for licensing waste burial sites except as it has yielded that authority to Agreement States. An "Agreement State" is a state which has an agreement with NRC which allows the state to regulate the receipt, possession, use and transfer of byproduct material and quantities of source and special nuclear material (SNM) not sufficient to form a critical mass, in accordance with regulations and procedures which have been concurred in by NRC. The state may license burial sites for disposal of radioactive waste. All sites are restricted in respect to the quantities of radioactive material that can be stored above ground prior to burial. SNM quantities limited under state licenses are 350 grams of ^{235}U or a combination of fissionable isotopes defined by the following formula:

$$\frac{Q}{200} + \frac{R}{200} + \frac{S}{350} = 1$$

where: Q = Plutonium in grams
R = ^{233}U in grams
S = ^{235}U in grams

Of the six commercial burial sites, the Illinois site is the only one not state licensed. The Sheffield, Illinois site is owned by the state, leased to NECO and licensed by the NRC; the Richland and Barnwell sites have, in addition to the state licenses, NRC licenses to bury SNM in quantities exceeding state licensable quantities (AIF, 1976).

All burial site licenses have been modified many times since their original issuance. Licenses are issued for a fixed time period, but as regulatory requirements change or as the needs of the burial site operators change, amendments are incorporated in the license. The Chem-Nuclear Manual (Barnwell) states that it shall be immediately revised when state or NRC requirements are changed or modified. Federal regulations require that the title to the land must be in the hands of a state or federal agency for a burial site to be established. Long term care of the site after termination of operation rests with the state or federal government. The states may collect fees from the operators and either place these fees in the general fund or establish a trust fund designated for perpetual care of the site; or the states may require a performance bond. The funds are intended to provide for routine monitoring and maintenance after site closure, as well as for minor remedial actions required in the event of radionuclide migration.

Hydrologic assessment is required as a portion of the licensing procedure for each commercial site. This assessment provides an estimate of the probability that ground and surface water is likely to contact the waste following burial, the pathways of ground water away from the burial site, the ion exchange or adsorptive capability of materials along that path, and the extent to which the radionuclide content of off-site ground and surface waters may be affected by the burial grounds.

Table 4-2 summarizes the licensing information for the six commercial burial sites.

4.2.2. Physical Characteristics and Waste Inventories

The design and construction of the waste disposal facilities at all sites are similar. Open trenches are used as the primary burial facility. The trenches are 60 - 250 meters long, 10 - 25 meters wide and range from 5 - 8 meters deep. Material excavated in construction of the trench is used as intermediate and final cover at the completion of waste disposal activities. In the high precipitation areas, provision for water collection and containment is made. These provisions may include: (1) grading to drain parallel with the proposed finished surface grade; (2)

TABLE 4-2

PRESENT STATUS OF

LICENSING OF COMMERCIAL BURIAL SITES

	West Valley	Maxey Flats	Barnwell	Sheffield	Beatty	Richland
Site Operator	Nuclear Fuel Services (NFS)	Nuclear Engineering Co. (NECO)	Chem-Nuclear Systems (CNS)	NECO	NECO	NECO
Site Ownership	State, leased to NFS	State, leased to NECO	State, leased to CNS	State, leased to NECO	State, leased to NECO	Federal leased to state, leased to NECO
Agreement State	Yes	Yes	Yes	No, (pending)	Yes	Yes
Activities licensed directly by NRC	Hull disposal area	None	Handling and burial of SNM	All Burial	None	Handling and burial of SNM
Activities licensed by State	All other	All other	All other	None	All other	All other
Burial of plutonium >10 nCi/gm	Restricted since 1974	Restricted since 1974	Never permitted	Restricted since 1975	Restricted since 1975	Restricted in 1979

installation of french drains in bottom of trench*; (3) sand or broken brick as lining for bottom of trench**; (4) sump pumps and stand pipes at low end of trench. Because of low precipitation at the Beatty and Richland sites, water collection is not provided for. Techniques to cover and seal the waste in the trenches vary by site. These techniques are discussed in Section 4.3.

The extensive ERDA Study, "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle" (ERDA, 1976), gives a summary of burial sites characteristics from many sources.

A typical burial trench diagram is presented in Figure 4-1.

Inventory of low-level radioactive waste buried at commercial facilities through 1978 is presented in Table 4-3.

4.3 Operating Procedures at Burial Sites

Review of the procedures manuals for Chem-Nuclear Services (CNS) and Nuclear Engineering Company (NECO) for operation of the Barnwell, Sheffield and Richland sites reveal similar patterns of operations (Barnwell; NECO, 1976; NECO, 1977) at all the sites operated by these companies. Major differences relate more to local climate conditions than to differences in company procedures. These procedures will be discussed in this section with the differences noted. Procedures related to occupational safety will also be discussed.

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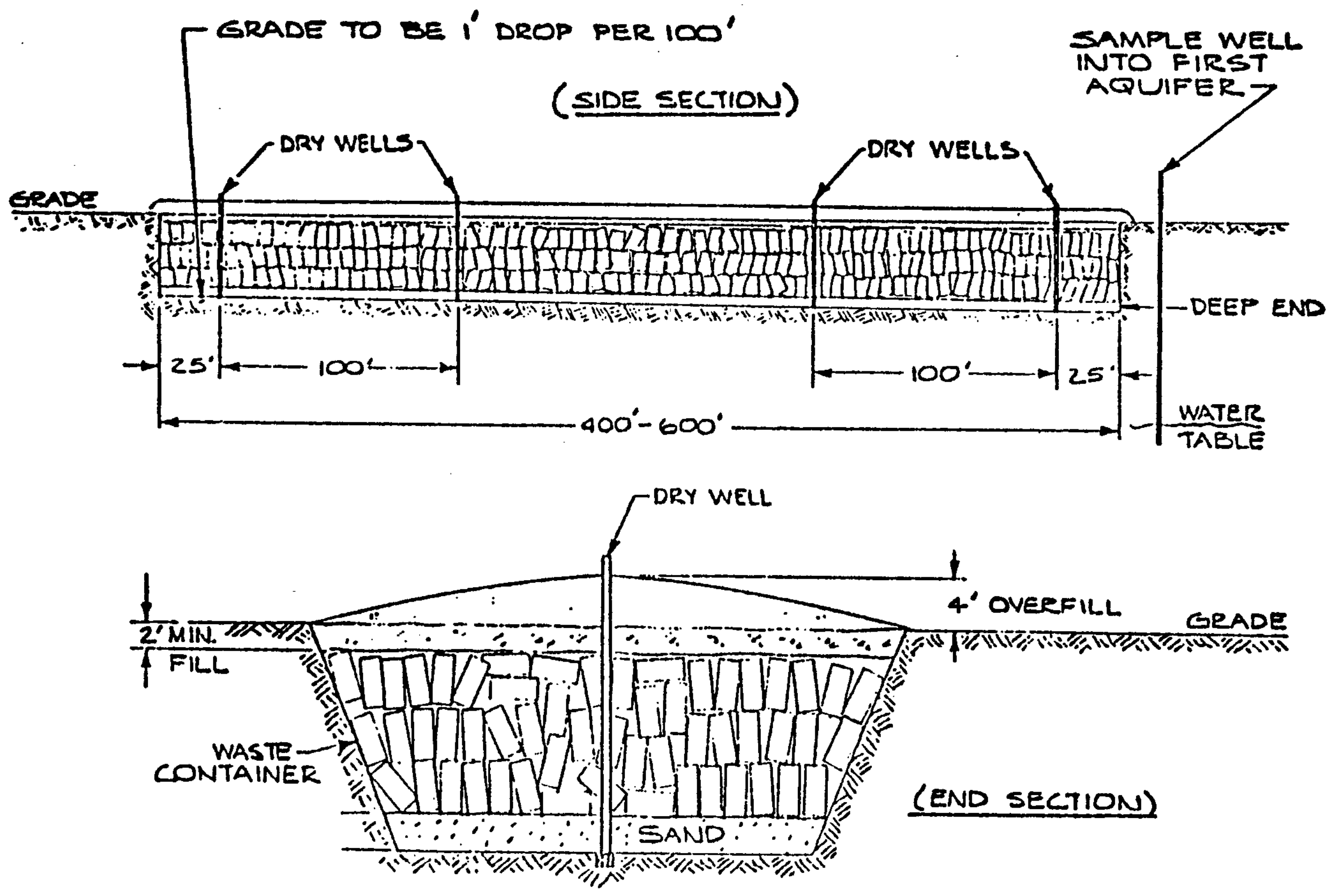
* A french drain is a depression in the bottom of the trench which extends for the full length of the excavation. The drain is filled with gravel so that water is conveyed to the low end of the trench.

** This allows any water in the trench to drain away from or have minimum contact with the waste and to flow without further contact to the collection area.



Courtesy of Chem-Nuclear Systems, Inc.

FIGURE 4-1

TYPICAL BURIAL TRENCH

(As Constructed at Barnwell, South Carolina)

(AIF, 1976)

TABLE 4-3

COMMERCIAL BURIAL SITE WASTE

INVENTORIES (AS OF 1/1/79)

(NRC COMPILATIONS)

Burial Site	Waste Volumes, m^3	By-Product Material, Ci	Special Nuclear Material, Kg.	Source Material, Kg.
West Valley	66,900	700,000	56.00	2,257,200
Maxey Flats	135,000	2,400,600	431.80	1,173,000
Barnwell	206,000	1,210,100	873.90	5,509,700
Sheffield	88,700	65,400	56.40	1,318,200
Richland	24,600	655,000	113.54	217,800
Beatty	70,000	161,600	199.13	690,400
Total All Sites	591,200	5,192,700	1,730.77	11,166,300

4.3.1 Receipt of Material

The starting point of the operation is the receipt of material at the burial grounds. The following actions are taken on receipt of a waste shipment at the site.

The Radiation Shipment Record (RSR) is presented and the shipment aboard the truck is inspected; inspection at this point is to insure that there are no leaks from the container and that the RSR is a correct record of quantity and physical form. Copies of RSR for use at CNS- and NECO-operated sites are included in Appendix E.

The DOT regulations concerning the shipment of radioactive material (49 CFR 173.393) determine the container the waste arrives in. There are no established state or federal regulations developed for burial containers. Current practice at burial sites is to bury waste in the same container in which it is received. The bulk of the waste is in 55 gallon steel drums. Very low level waste may be in fiberboard or wood boxes. Shielding casks which are reusable for future shipments have waste packaged in drums or liners which can be removed from the cask at the burial site.

4.3.2 Disposition of Materials

Once the RSRs are verified, the normal procedure is for the delivery truck to drive to the trench and off-load by random dumping of packaged material. Generally some effort is made to stack or position these wastes. The trenches are filled from the high end to the low end. Effort may be made to preserve the container integrity by placing the heaviest containers at or near the bottom of the trench, although this does not appear to be a requirement. Certain materials such as large pieces of equipment which, if left in the DOT package would create a void, are removed from the package. Low specific activity waste such as ore residue, earth or masonry rubble may be accepted without packaging at some trench sites.

Individual procedures for disposition of SNM, material from shielded casks, sealed sources and caisson burial vary from site to site; and the procedures are primarily concerned with radiation protection or

assurance that the SNM is separated from other SNM material and properly marked.*

4.3.3 Operational Backfill and Trench Closure

4.3.3.1 Backfill

As waste material collects in an operational trench, it is covered with a 6" layer of previously excavated material when one of the following conditions occurs:

(1) The radiation level exceeds occupational exposure levels specified in license.

(2) The waste material reaches a level 2-3 feet below the edge of original grade of trench.

There may be, in addition to the previous conditions, a requirement dependent on weather. Barnwell reported that backfilling is done daily; the Sheffield license states no waste "shall be left uncovered for a period exceeding two calendar weeks, weather permitting". When a container ruptures during the unloading process, it is to be covered immediately under the supervision of the Radiation Safety Officer.

4.3.3.2 Trench Closure

In the high precipitation areas, when the trench is filled, it is covered with an additional compacted layer of clay (1-2 feet thick). A mound of soil (approximately 4') is added which is graded to the natural drainage pathway away from the trench. This mound is seeded with a shallow rooted ground cover within one year of closure.In the low precipitation areas, the trench is covered with a mound of earth five to eight feet thick in the center and three feet thick at the edges. This is then covered with a layer of cobbles.

*The total quality per package and package spacing is required to assure subcritical arrays.

4.3.4 Environmental Monitoring Program

The existing environmental programs are directed towards two goals:

(1) to detect any movement of radioisotopes from the burial trenches to the environment, and

(2) to provide a continuing record of the condition of the site, particularly with respect to the long term containment of radioactive waste disposed of at the burial site.

Details of the monitoring programs are a function of various site-specific parameters such as the operations occurring on the site, the meteorological and geological conditions, the type and concentrations of radionuclides accepted for burial and the local population profile.

In general, four types of samples are taken for analysis. They are as follows:

(1) Aqueous samples

  (a) from sump monitoring locations - these are located in the french drain sump or at the ends of completed disposal trenches;

  (b) at the level of first aquifer immediately below trench and at specified areas at that level on the burial ground;

  (c) from surface runoff sampling stations located in the surface water runoff paths

  (d) from wells both on and off site; and

  (e) from bodies of surface water within immediate environs of the disposal site.

(2) Soil and Flora Samples - on site and within local environs.

(3) Fauna Samples - may be feasible to utilize feces or local fauna by-products to provide indicators.

(4) Air Samples - continuous air sampling during operation at a location normally downwind from burial trenches. Air sampling is also suitable for meeting occupationally exposed personnel requirements.

NECO has established a radioanalysis program to be utilized in the analysis of all environmental samples taken at NECO sites. These analytical procedures are included in Appendix F. Each NECO site uses these procedures and sets up a monitoring program applicable to that specific site's characteristics. Frequency of sampling is given in the Site Operations Manual. Sample analysis, action levels and contingency actions are also included in each manual. The Chem-Nuclear, Inc. program for the Barnwell site is included in Appendix G.

4.3.5 Occupational Exposure Monitoring

Radiation protection policy for employees on the burial ground site and visitors to the site is in accordance with state or NRC regulations for allowable dose limits. Each policy statement includes instructions for record keeping, individual monitoring, training of personnel, supervision, decontamination methods, definition of controlled areas, worker protection devices and emergency procedures. Personnel monitoring devices include thermoluminescent dosimeters (TLD), film badges and pocket dosimeters. The exposure is continuously monitored. Routinely, there is also an annual whole body count for each employee. Other bioassay procedures, such as urinalysis are conducted upon unusual exposure.

The Chem-Nuclear Manual states:

> "CNSI operations involve, for the most part, exposure to gamma radiation being emitted by materials contained within waste containers. All CNSI personnel shall be alert, however, for the possibility of ruptured and/or leaking containers which could lead to ingestion of radioactive material or skin contamination."

Clearly, if any of these leaking or ruptured containers contained chemically toxic materials, the danger of ingestion of or skin contamination by chemically toxic material would be present. Therefore, concern must be given to the occupational exposure hazard of the employee or visitor in the study of the toxicity of low level wastes.

Certain procedures used for radiation protection will in most cases afford a high degree of protection to the worker from toxic chemicals. Protective clothing, which may include shoe covers, gloves, overalls, and lab coats, is provided by the site management. The management also maintains this clothing. Inhalation protective devices, such as face masks, ventilation hoods, etc., are used by the workers under the procedures described in the Radiation Procedures Manual. This manual also contains the training procedures developed by the management to orient the workers in the proper use of these protection devices.

4.4 Summary

The states and, in the case of the Sheffield site, the Federal Government have the responsibility for defining the safety provisions for site operations, inspections during operation, decommissioning and long-term surveillance. The management of burial sites is a long-term operation, and currently this long-term care belongs to the state or federal agencies as described in Section 4.2.1 Because of the decay properties of radioactive material and the low specific activity of this waste, at some future time the hazard of the radioactivity may be judged to be sufficiently low as to release some of the long-term controls. This time period has not been defined, but has been postulated as a few hundred years (DOE, 1978). Evaluation of toxic chemical release from the waste to the environment should include the possibility of decommissioning and/or other use of the site at some future time. Decommissioning and reclamation of the site are currently being studied by the NRC (FBDU, 1978; Murphy, 1978) for the purpose of obtaining guidance to develop criteria for regulations relating to low-level waste management. The NRC Task Force Report (NRC, 1977) has recommended federal ownership of the land and administration of a long-term care program. Future constraints on use of the site are being evaluated in terms of exposure to the public of radiation which might exceed limits as defined by

federal regulatory agencies. Unrestricted use would mean that no constraints are placed on the use of the property and all potential pathways for exposure to the public would have to be considered.

The following statement is made in the Environmental Report for Sheffield.

RECLAMATION AND RESTORATION

> "When burial operations are terminated, experimental reclamation projects may prove effective for reclamation and restoration of the site to its previous condition. Monitoring surveillance and site maintenance will continue. Limited uses can be made of the land in the forseeable future. Vegetation and wildlife will be left to natural successional development in the buffer zones."

Figure 4-2 from the same report shows possible pathways for transport of radioactivity to man. Similar pathways could be postulated for chemical migration.

During the operating phase and after closure of site while under care of the state or federal government, the single most important factor affecting the containment capability of a burial ground is the degree to which ground and surface water can contact the waste and subsequently cause migration of any residual toxic materials.

Many factors govern the movement of waste as leachate through the soil. Water movement associated with particular geologies and chemical reactions within the soil profile affect the transportation and retention of contaminants through the soil (Van Hook, 1977). Many soil reactions are pH dependent. Some contaminants may interact with the soil exchange complex and become more or less soluble. Microbial transformation and degradation may affect the soil profile; for organic constituents of waste, this is probably the most important consideration. Since these factors are peculiar to each site, they must be evaluated specifically in relating the chemical hazard to the probability of release to the environment at that site.

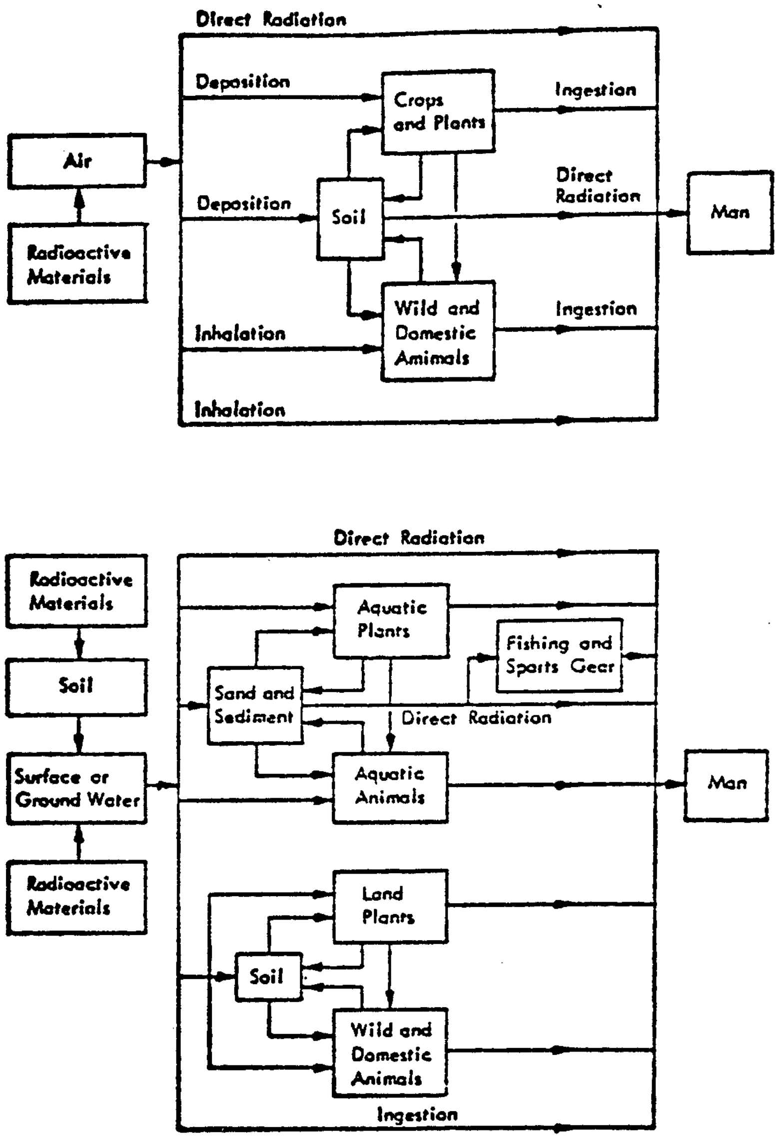


FIGURE 4-2

RADIATION PATHWAYS

Sheffield LLWD Site
Nuclear Engineering Company, Inc.

However, the operating practices as described in this section and the composition of waste material described in Section 2.0 of this report may be expected to be similar at all commercial burial sites.

5.0 PERSISTENCE AND MOVEMENT OF CHEMICALS AND LOW-LEVEL WASTES

5.1 Methodology

The environmental hazards posed by waste constituents at low level waste burial sites depend both on toxicity (from radioactivity and chemical activity), and on the likelihood that constituents will escape containment. If escape occurs, wastes may come into contact with sensitive components of the biosphere before natural processes degrade or immobilize the toxic constituents. The purpose of this chapter is to summarize the transport processes which may enhance the mobility of waste constituents, to summarize the natural removal/degradation processes which may occur, and to establish a framework to rank waste constituents in terms of their relative ability to escape and pose hazards within the environment.

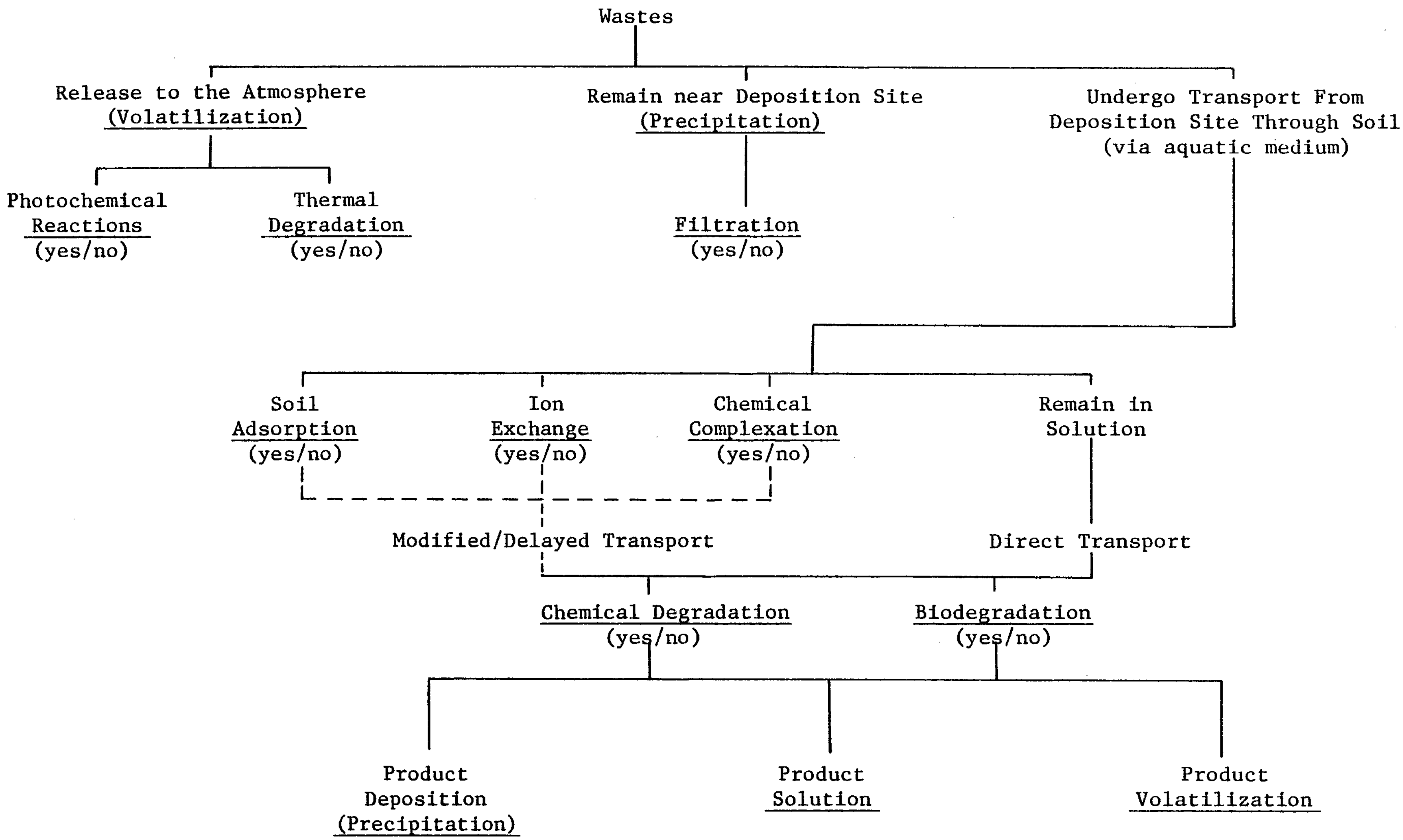
5.1.1 The Evaluation Framework

As shown in Figure 5-1, there are several alternative pathways and potential degradation processes which should be considered in the evaluation of the movement and loss of wastes from a burial site. The major pathways include release to the atmosphere, precipitation or filtration processes near the site of deposition, and aqueous transport from the deposition site. In low level waste burial sites, aqueous transport from the deposition site is an important potential pathway for movement and degradation of waste materials.

Volatile materials may escape to the atmosphere after migrating upwards through the air-filled spaces near the surface of a porous-disturbed soil. An example of such a volatile waste constituent would be toluene. However, few original waste materials are likely to be so volatile that this represents a major direct pathway. It is more likely that after a sequence of reactions in the burial site, degradation products will constitute the escaping volatile material. Once released, exposure to sunlight may enhance the degradation of reactive organic compounds by photochemical reactions. In addition, thermal energy may also contribute to the eventual dissipation and degradation of volatile organic compounds.

Figure 5-1

Transport and Fate of Waste Constituents From Low Level Burial Trenches



The chemical characteristics of the environment at and near the burial site may cause the formation of insoluble precipitates. Loss of oxygen from sulfates, for example, will facilitate formation of insoluble metal sulfides.

Other poorly soluble compounds include metal halides, metal hydroxides, and metal carbonates. Once precipitation has occurred within the soil medium, the product material will be deposited rapidly onto the relatively large available pore surface area. Poorly soluble metal salts will probably be immobilized unless conditions change in the trench to cause molecular transformations of the salts into more soluble forms. In some instances, strong acids have been introduced to effect urea-formaldehyde polymecization in situ to solidify wastes in the trench. This practice is an example of an intentional addition of a strong acid to a trench which may have been used to solidify wastes at a disposal site in the past, but it is no longer a recommended practice.

Waste constituents which are not volatilized or precipitated will eventually be transported by means of water moving through the porous medium and away from the initial site of deposition. Even relatively insoluble materials eventually can migrate by this means. Water flow may be continuous or intermittent, and may be in a water-saturated pore space or within a partially saturated pore space.

Given such a variety of possible conditions, there are several processes which can influence the rate of movement and the ultimate fate of the constituents in a burial site. Soil colloids are extremely complex and provide a large surface area for promoting numerous physical-chemical processes and interactions between constituents. Many adhesion mechanisms apply: non-polar Van der Waals (absorption) forces, hydrogen bonding, (interactions around a hydrogen atom), cation or anion exchange, or the formation of coordination complexes. These processes are unlikely to immobilize a constituent. However, adhesions to the soil matrix usually will delay the mass transfer (reducing the rate of movement of a

particular constituent relative to the flow of water). Also the diversity of potential degradation reactions and surface interactions is increased as the retention time of wastes in soil is increased. Degradation occuring within the soil medium will most likely involve either direct chemical reactions or biodegradation. Most organic compounds eventually can be used as a nutrient source by microorganisms (e.g., bacteria and fungi). Complex organic substances may be broken down into fundamental chemical compounds (methane, carbon dioxide, water, etc.) by microbial degradation. Even materials toxic at high concentrations to organisms may be subject to biodegradation. Both organic and inorganic material may be assimilated by biota; however, inorganic constituents, such as metal ions, are more likely to become consolidated in mineral formations.

These processes, as they apply to waste constitutents of particular interest found in trench waters, will be discussed more specifically in Section 5.2.

5.1.2 Geological and Hydrological Factors at a Site

Geological and hydrological factors determine the extent of water contact with wastes, including rates of movement, and in large part, the ultimate destination. Environmental characteristics that may be affected by geological and hydrological factors are summarized in Table 5-1. Substantial control over these factors is a significant requirement for any satifactory waste management strategy.

Composition and rate of production of leachate (the aqueous solution moving toward groundwater from the disposal site) are strongly influenced by site-specific conditions. Factors exerting an influence on leachate composition include the pH of the solution, oxidation-reduction potential, the chemical composition of solids and liquids which are contacted, facility design, water flow, and temperature. Factors which influence the solubility and rate of solution for constituents in leachate include the oxidation state of inorganic compounds, oxidation-reduction insert

TABLE 5-1

Environmental Characteristics of Waste Disposal Sites That May be Affected by Geological and Hydrological Factors

Geological/Hydrological Factor	Environmental Characteristics that May be Affected
Meteorology/Climatology	
Precipitation (Quantity, Type, Pattern)	Quality, quantity, depth and flow of surface/sub-surface waters
Temperature	Kinetics of chemical reactions; microbiological activity
Evapotranspiration Rate	Infiltration rate: quantity and flow of surface/sub-surface waters
Topography	Runoff and infiltration of precipitation Configuation, slope and depth of water table Recharge and discharge of groundwater
Surficial Material	
Type, e.g., glacial, alluvial, aeolian	Permeability, porosity, stratification
Thickness	Water storage capacity
Composition	Ion exchange and adsorption capacities, water quality, pH, complexation capacity, chemical reaction kinetics
Texture	Ion exchange and adsorption capacities, permeability, porosity, water storage capacity, compaction
Structure	Porosity, permeability, aeration
pH and Buffer Capacity	Waste solubility, chemical reaction rates, microbiological activity, adsorption and ion exchange capacities
Ion Exchange Capacity	Waste concentrations, chemical reactions
Temperature	Waste solubilities, chemical reaction kinetics, microbiological activities
Porosity	Permeability, aeration, filtration
Permeability	Hydraulic productivity, groundwater flow
Stratification	Physical, chemical and hydrological properties
Adsorption Capacity	Waste concentrations in solution, availability for chemical, physical, and biological activity
Bedrock Material	
Type	Permeability, porosity, bedding
Permeability	Rate of water flow
Composition	Water quality
Dip	Topography
Hydraulics	
Degree of Saturation of Geologic Media	Rate of water movement
Amount and Geometry of Pore Spaces	Permeability
Fluid Properties (density, viscosity, surface tension)	Rate and pattern of water movement
Hydraulic Connections with Surface	Groundwater recharge and discharge, rate of movement
Head Distribution	Rate and direction of water flow

potential, ionic strength (the quantity of dissolved ions), the availability of complexing and chelating agents, particle size for material subject to removal,and solution pH. Microbiological activity may also affect leaching rates by altering the chemical form of the waste constituents.

The nature, size and degree of interconnection of pore spaces within the soil determine the permeability of the geologic formation. This typically controls leachate mobility. However, fine particles from decomposing waste may plug pore spaces and significantly affect permeability. Permeability varies widely with soil or rock type and bedding. For example, clay, sand, and gravel may have permeabilities with corresponding ratios of 1: 1000: 5000, respectively. The discharge measured in gallons per day through an area of 1 square foot, under a hydraulic gradient of 1 ft/ft^2. Corresponding fractional porosities for clay, sand, and gravel are in the ratios 0.45: 0.35: 0.25, respectively. These ratios suggest that the effective porosity is affected to a greater extent by the tortuous nature of microscopic flow paths than by the amount of open pore space.

Geological formations tend to be a composite of materials in many instances. They also may be stratified or fractured. Zones of high permeability tend to parallel or coincide with formation boundaries. Since fluids preferentially follow permeable pathways, stratification may play a very important role in mobility of wastes.

Some sort of bedrock underlies most sediments, constituting materials highly impervious to fluids. With this "basement", fully saturated pore spaces usually extend upward to a top surface, the water table. Above the water table there is an unsaturated zone; (a zone of permeable soils, etc., extending up to the soil surface). The thickness and composition of this material is particularly important to the selection of waste disposal sites. If the unsaturated zone is thick and with a high fine silt and clay mineral content, it will act to retain pollutants. Such a condition would be less permeable and may promote

"bathtubbing" in the disposal trench. Leachate mobility can be strongly influenced by the capacity of soil for adsorption and ion exchange processes. Furthermore, a relatively aerobic unsaturated zone may permit contact with a greater variety of microorganisms. Similarly, an anaerobic unsaturated zone can also permit contact with anaerobic microorganisms. This may enhance biodegradation and, therefore, increase the probability that complex-toxic compounds will be transformed into simple, harmless products before transport to the groundwater.

The configuration of the water table and mobility of groundwater within it also are important. These factors determine the rate and direction of eventual lateral movement, such as gradual movement which might intercept a well field or surface stream leading to contact with larger more complex organisms. Table 5-2 summarizes the physical and chemical factors associated with waste materials and the geohydrology of the burial site which may influence the potential environmental hazards of low level wastes.

The pH of trench leachate measured at the Maxey Flats site varied from 2 to 10 (Columbo, et al., 1977). The low pH leachate was found in trenches which contained substantial amounts of urea-formaldehyde from direct in-trench solidification activities. Urea-formaldehyde solidification processes involve a condensation reaction which produces an acid free standing liquid. In normal trenches a leachate pH between approximately 6-8 would be expected.

5.2 The Transport and Fate of Representative Toxic Chemical Wastes

This section addresses the factors which influence the transport and fate of representative toxic compounds from the groups of chemicals identified at Maxey Flats (see Tables 2-1 and 3-2). Chemical compounds divide naturally into two groups, organics and inorganics. Selected inorganics that are representative of metals found in low level waste burial sites include: barium, cadmium, chromium, copper, lead and zinc. Representative organics include: 1,4-dioxane, oxalic acid, diacetone alcohol, 1, 1, 1-trichloroethane, 1-

TABLE 5-2

Geohydrological Properties of Waste Materials and Waste Burial Sites Which May Alleviate Environmental Hazards Due to Waste Disposal

Factor Classification	Factors which Retard Material Transport	Factors which Enhance Material Degradation
<u>Physical</u>	High adsorption capacity - - - - - - - - - - - -	Low adsorption capacity
	Low precipitation	
	Low water infiltration/exfiltration from trench	
	Low permeability unless "bathtubbing" occurs	
	Low leachate volume compared to total wastes	
	Low eluant to solid ratio	
	High filtering capacity	
	Low hydraulic gradient	
	Low soil moisture content	
	Low groundwater flow rate	High temperature
		Soil aeration
		Large waste material surface area
<u>Chemical</u>	High adsorption capacity - - - - - - - - - - - -	Low adsorption capacity
	Low waste material dissociation constant - - -	High waste material dissociation constant
	Low waste material solubility in water - - - -	High waste material solubility in water
	Presence of complexing/chelating agents*	
	Alkaline pH - - - - - - - - - - - - - - - - - -	pH of 6-8
	High ion exchange capacity	
	Chemical precipitation	High microbiological activity (aerobic/anaerobic)
		High chemical reactivity of waste material
		Low stability regarding pH
		Low stability regarding temperature
		Presence of chemical catalysts

*May retard or enhance transport, depending on specific conditions.

octanol, 1, 1 diethoxyethane, o-, m-, and p-cresols, toluene, and di-2-ethylhexyl phathalate. All these materials have been reported in trench waters at The Maxey Flats low level waste site. Some of the most significant factors that affect the transport and fate of inorganic and organic materials are discussed in subsections 5.2.1 and 5.2.2, respectively. Also included are brief discussions of the transport and fate of the specific representative elements and compounds.

5.2.1 Inorganics

The inorganic compounds consituting representative toxic chemicals all may be classed as heavy metals. The two most important processes in the natural removal of heavy metals from water are ion exchange and precipitation. A substantial number of other processes and factors affect the relative rate of removal and ultimate quantities removed. Because the removal process occurs at the molecular level on the surfaces of very small mineral grains or colloids, the precise chemistry of the removal process is relatively unknown. In addition to difficulties arising from the submicroscopic sizes of the particles involved in removal of metals from water, the chemistry is often complex due to the large number of chemical components present in soil. Therefore the discussion of these processes in the literature and in this analysis is necessarily more qualitative than quantitative.

The metals barium, cadmium, chromium, copper, lead and zinc are chemical elements and not subject to degradation processes as organic chemicals are. However, if these metals are bound to organic compounds, then the degradation of the organic substances may eventually return the metals to their inorganic forms and may affect the transport process.

The soil is a complex zone of interaction between rock, water and air. As such it cannot be treated in terms of static equilibria. Chemical equilibrium equations can only be used as guidelines in understanding soil interactions. Chemical kinetics are related to the process known as reversion, which is the change from a more

soluble to a less soluble form of a substance which has been removed from water. When a substance is first removed from solution it is generally attached to a surface in a relatively disordered manner, such as through ion exchange. The substance may slowly revert to more ordered compounds through a different and relatively slow process such as crystalization. For example, hydrated calcium sulfate yields a hard crystalline solid (hemihydrate and dihydrate) which is extremely stable.

The processes of chemical, thermal and biological degradation will be discussed only as they affect organic constituents to which the metals Ba, Cd, Cr, Cu, Pb and Zn are bound. Likewise, since metals are not volatile and cannot be decomposed, volatilization and photochemical reactions are not relevant removal processes. It is assumed that no hazardous volatile organo-metallic compounds are present. This assumption is based on the premise that organic carbon decays in a landfill, leaving primarily inorganic constituents. Filtration and soil adsorption will generally be discussed in terms of precipitation and ion exchange processes. The terms filtration and soil adsorption are generally used to describe the removal of heavy metals from water, but with soil, water and wastes more specific processes will to be discussed.

5.2.1.1 Ion Exchange

Ion exchange in soils is a process involving the attraction of positively charged ions for negatively charged surfaces on clays or organic matter. The ability of a soil to hold cations is defined as its cation exchange capacity. Generally soils which are fine textured have much higher cation exchange capacities than coarse textured soils since the surface area exposed to water of a fine soil is much greater than that of a coarse soil. Pure sand or gravels have negligable surface area as compared to clay or humus. Some substances may have surface areas as large 100 m^2/gm of soil. Therefore the cation exchange capacity (CEC) of a soil is a direct function of its content of clays

and humic material. The humic acids in soil have the highest cation exchange capacities, followed by the montmorillonite group of clays. The cation exchange capacity is a direct measure of the ability of the soil to remove the metals under consideration from solution. Since waste burial will be located under the topsoil where most organic matter is present, the clay content of the waste burial site will be the most important factor in determining the capacity of the soil to remove heavy metals. The pH of the water (which will be discussed later) is the most important factor affecting the capacity of the clay to hold cations.

If the leachate from a waste disposal site is able to reach a zone of fractured bedrock where the water interacts with a small surface area and relatively few clay minerals per unit volume, then removal of heavy metals from the leachate will not occur or will occur very slowly. Likewise, leachate that escapes the disposal area and becomes part of surface runoff will not be naturally purged of heavy metals. Even if processes of precipitation or adsorption occur, the fine grained substances onto which heavy metals are deposited will migrate substantial distances in runoff. Therefore, to ensure that heavy metal concentrations do not exceed safe levels in leachate, care must be taken to keep them within areas in the ground with high concentrations of clay minerals. Clays also are very impermeable to water and thus allow only very slow leachate migration. Mixtures of clay and more permeable materials such as sand show a substantial decrease in permeability from introduction of clay. When either no water is present or no flow of water is allowed due to negligible permeability, the heavy metal wastes do not migrate and would not present an off-site environmental hazard, except in the case of a "bathtubbing" effect.

The affinity of a cation for an ion-exchange site on a clay mineral is a function of its charge and <u>hydrated</u> ionic radius. The

general trend is $Cs^+ > K^+ > Na^+ > Li^+$ and $Ba^{++} > Sr^{++} > Ca^{++} > Mg^{++}$. Evaluation of the transition metals is more complex because they differ in their "d" atomic orbitals as well as in their hydrated ionic radii. According to Fuller _et al_., (1979) the mobility of selected heavy metals varies with Cu<Pb<Zn<Cd<Ni<Hg. This mobility is affected by factors other than ionic radii and charge and also involves more than just ion exchange. For example, the mobility of Ca^{++} is equal to that of Zn^{++} at pH 5.5, but at pH 7.0 Ca^{++} is substantially more mobile (Leeper, 1978). The presence of anions including sulfates, nitrates, and halides can also influence mobility.

Most of the cation exchange sites are usually filled by Ca. However, the heavy metals Cr, Ba, Pb, Cu, Zn and Cd compete favorably or equally with Ca for cation exchange sites and these heavy metals will be adsorbed until the ratio of adsorbed ion to dissolved ion is equal to or greater than the ratio of adsorbed to dissolved calcium. Therefore initial strong adsorption of heavy metals occurs in previously unpolluted soil due to ion exchange. If the more mobile ions of H^+, Na^+, and K^+ are initially more abundant than heavy metals and divalent cations such as calcium, then the adsorption of heavy metals will be even stronger.

Both ion exchange and the formation of insoluble hydroxide precipitates are very strongly pH dependent (Figures 5-2, 5-3 and 5-4). A solubility change of two orders of magnitude can result from a change in pH of one. Note the change in log molar concentration for Zn^{++} from 10^{-1} to 10^{-5} between pH 6 and 8 in Figure 5-4. Acidic pH conditions are extremely detrimental to the removal of most heavy metals from solution. Maintaining a pH of greater than 7 by the traditional practice of liming the soil reduces the movement of most heavy metals by greatly decreasing their solubility.

FIGURE 5-2

Theoretical Adsorption of Fe^{+3}, Cr^{+3}, Co^{+2}, and Ca^{+2} on SiO_2 from 10^{-4} M Solution as a Function of pH

Leeper (1978)

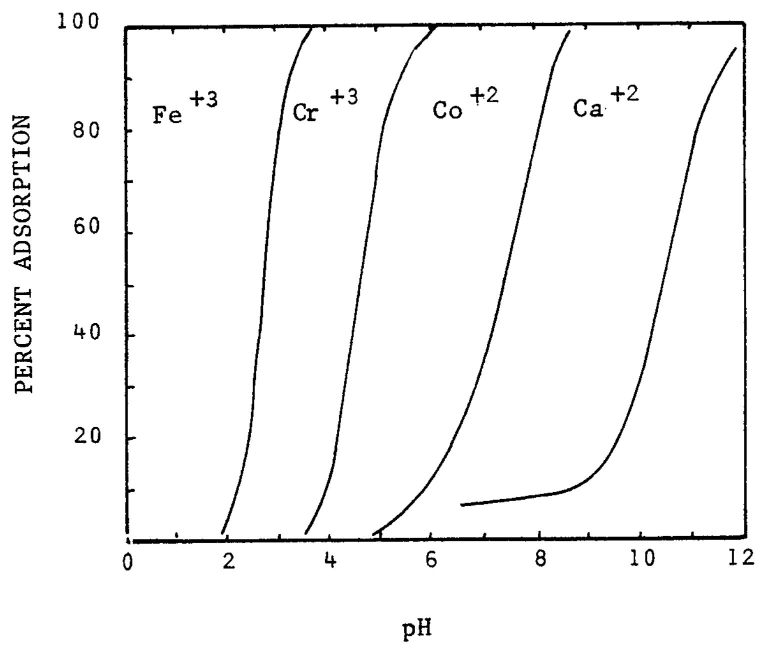


FIGURE 5-3

Free Metal Ion Concentrations in Equilibrium with Solid Oxides or Hydroxides

Higgins (1979)

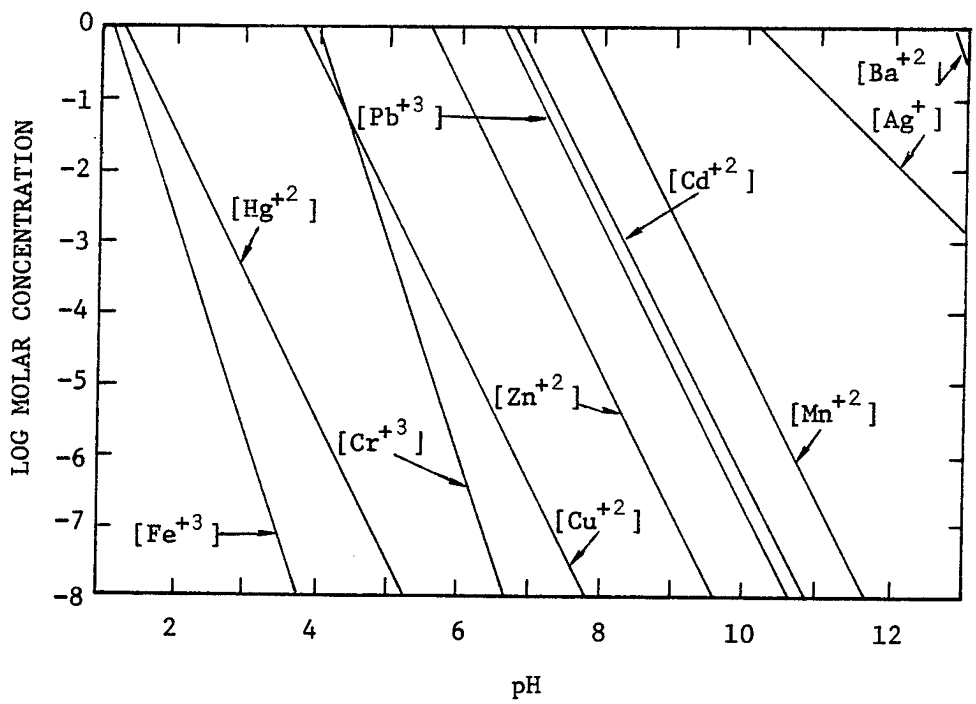
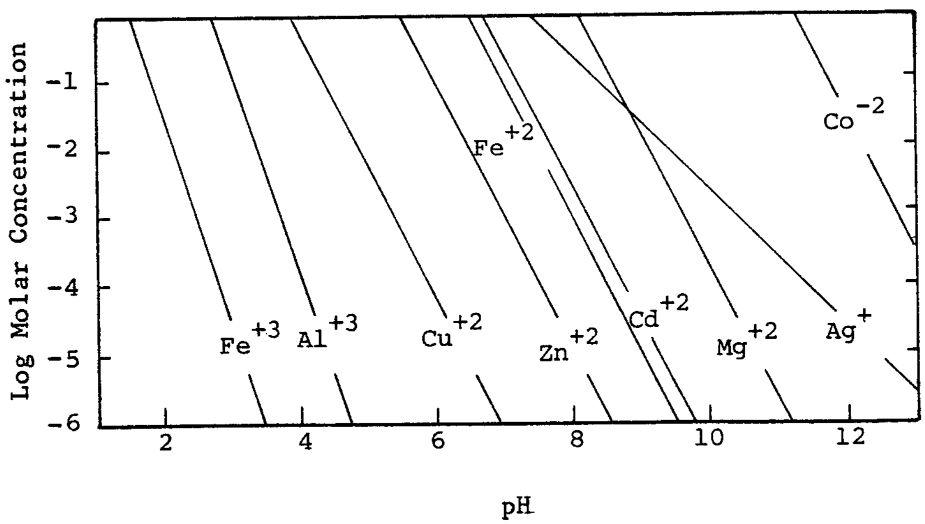


FIGURE 5-4

Solubility of Oxides and Hydroxides. Free Metal Ion Concentration in Equilibrium with Solid Oxides or Hydroxides. The Occurrence of Hydroxo Metal Complexes Must be Considered for Evaluation of Complete Solubility. Stumm and Morgan (1970)



5.2.1.2 Precipitation

The precipitation of insoluble hydroxides is extremely pH dependent. Also, in most cases the precipitation of other heavy metal compounds is pH dependent. For example, precipitation of heavy metals as sulfates, sulfides, phosphates and carbonates depends on the abundance of anion and oxidation-reduction conditions as well as pH. Also, since heavy metals may co-precipitate with iron and manganese hydroxides, the concentrations of Fe^{++} and Mn^{++} and the pH and oxidation-reduction (eH) are important in determining the precipitation of heavy metals.

One factor which may increase the solubility of a metal is the formation of a soluble complex. Due to the presence of unfilled d-orbitals the formation of chemical complexes with certain transition metals is favored. Zn^{+2} has a filled d-shell so formation of a highly ordered complex would be unlikely. A series $Mn^{++} < Fe^{++} < Co^{++} < Ni^{++} < Cu^{++}$ of increasing complex stability can be derived by this rule (Stumm and Morgan, 1970). According to this rule copper will form the more stable soluble complexes. Chromium may become soluble under certain complex formation conditions, but barium, zinc, cadmium, and lead form essentially insoluble complexes. Indeed, copper is stable in solution as a carbonate complex or a hydroxide complex depending on pH. However, the formation of organic chelates or the formation of soluble complexes may increase heavy metal solubility for elements other than copper. Organic matter generally adsorbs heavy metals. However, if certain organic species are present the formation of a soluble organometallic molecule called a chelate is possible. Chelates may be important in increasing the solubility of metals in humus-rich soil, but when little or no organic matter is present the formation of chelate complexes in soil is unlikely. Also, when organic matter is present, biodegradation of the organics may release

metals that were previously bound to organic colloids. Thus organic matter in soil may slow the movement of heavy metals but the eventual decomposition of the organic matter releases the associated heavy metals.

5.2.1.3 Adsorption Isotherms and Relative Heavy Metal Mobility

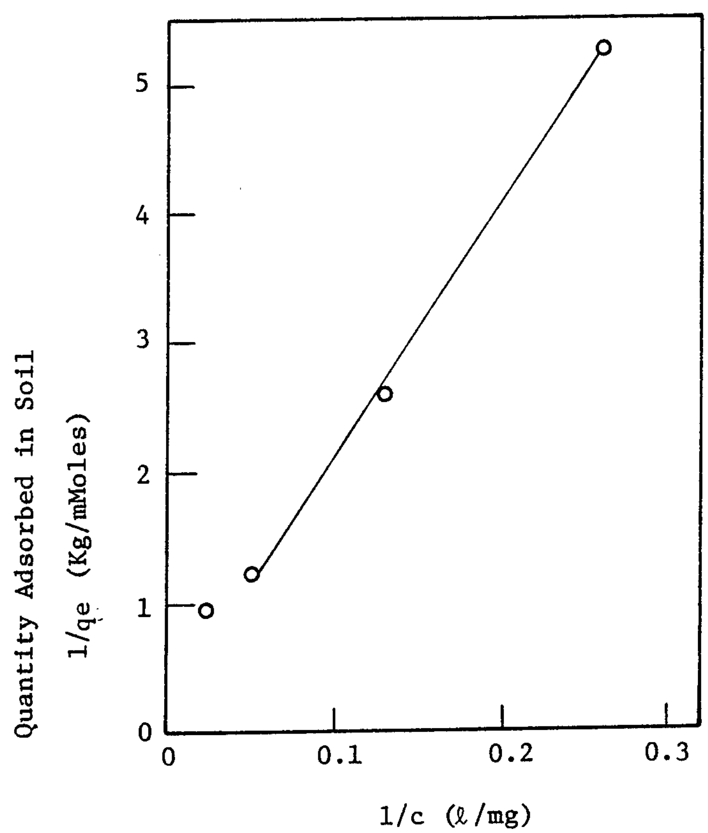
Heavy metals transported in water solution are removed by adsorption-type processes and attachment to the surface of soil particles. An empirically-derived Langmuir-type adsorption isotherm can be used to describe the relationship between quantity of ions in solution and that sorbed on surfaces. A typical isotherm for adsorption of cupric ton on Providence silt is shown in Figure 5-5, and for adsorption of cadmium and nickel on Arizona silty soil in Figure 5-6 (Higgins, 1979). Ion exchange is one possible attachment process, and often the important one. But other attachment processes also are possible. For some cases it has been suggested that the heavy metals are precipitated by metal oxide or hydroxide formation on surfaces with coprecipitation of other metals into the oxide.

Empirical data indicate that the precipitation reactions can occur rapidly and relatively high concentrations of metals in solution may become substantially decreased. (Higgins, 1979; Frost and Griffin, 1977). Data from carefully monitored test injection of wastewater into shallow aquifers show the half-life at a monitoring well for arrival of cadmium to be about 50 times as long as for arrival of the carrier water (Roberts, et. al., 1979). Similarly, half-lives for arrival of copper and silver were about 100 times as long as for water. This translates into very substantial residence time for these metals within a typical porous soil.

The equation describing mobility of the adsorbed material relative to water mobility can be given as:

FIGURE 5-5

Adsorption Isotherm for Copper (Cu^{++}) in Contact with Providence Silt Higgins (1979) (adapted from W. E. Nelson, "Fate of Trace Metals in Subsoils as Related to the Quality of Groundwater", Final Report for OWRT, Project No. OWRT-8-028-ALA)

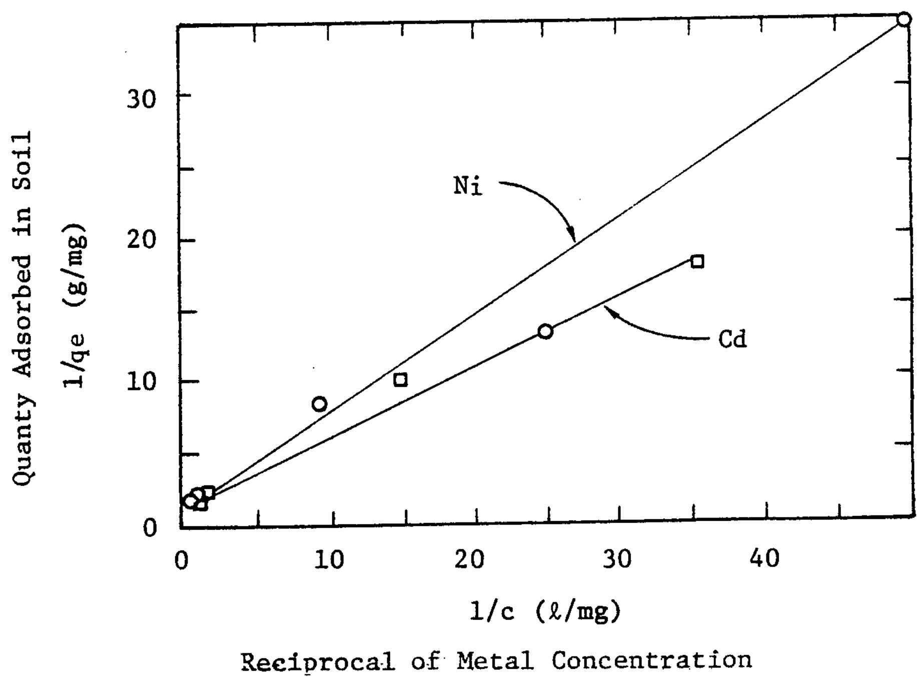


Reciprocal of Metal Concentration

FIGURE 5-6

Langmuir Adsorption Isotherms for Cd and Ni with Arizona Silty Soil (200 ml treated wastewater/2 g of soil).

Higgins (1979)



$$v/v_w = \frac{k}{k + da/dc}$$

where: v = velocity of the metal
v_w = velocity of the water providing mobility
k = an appropriate dimensionless constant
da/dc = slope of the adsorption isotherm for a quantity adsorbed from a concentration in solution c.

For strongly adsorbing compounds for which the isotherm slope is large, relative mobility of the metal will approach some low residual value. High concentrations may permit saturation of adsorption sites, for which the slope of the isotherm goes to zero. Consequently, any additional dissolved material may be transported with the speed of the water which provides mobility. There are methods available to model more complex processes, particularly as concentrations increase. (Flowers, 1971).

5.2.1.4 Processes Important to Individual Elements

Discussion relevant to the transport and eventual fate of individual elements is presented below. Significant physical/chemical processes comprise oxidation, hydroxide formation, complex formation, precipitation, coprecipitation, rates of solution for various molecular forms, and interactions on available surfaces. The pH of the aqueous phase is most significant in determining the transport and fate of individual elements. With few exceptions, most elements are relatively immobile at neutral or alkaline pH.

Barium

Barium may be as abundant as 1% in soil but generally does not harm plants due to its low solubility (Leeper, 1978). Barium sulfate

(barite, $BaSO_4$) is quite insoluble under normal conditions as is barium carbonate (witherite). Barite is more important in removing barium from solution under acidic conditions since witherite is more stable under alkaline conditions. According to Leeper (1978) the rather obscurely known mineral gorceixite Ba Al_3 $(PO_4)_2$ $(OH)_5$ H_2O may be important in decreasing the solubility of barium in soil. Poorly known phases such as this may be very important in determining the concentration of heavy metals in water, but our lack of knowledge concerning them makes evaluation of their importance difficult. It is possible that barium solubility could become undesirably high under acidic-reducing conditions where carbonate and sulfate stabilities are decreased. Barium forms relatively soluble sulfide complexes which might exist under acidic reducing-conditions, at a burial site. $BaCl_2$ and $Ba(NO_3)_2$ are quite soluble as are the chlorides and nitrates of the other heavy metals under consideration.

Cadmium

Cadmium forms relatively insoluble carbonates, hydroxides and phosphates. The chemistry of cadmium is very similar to that of zinc. However, zinc is an essential trace element for human health while cadmium is toxic at extremely low concentrations. The EPA drinking water standard for Cd is 10 parts per billion (ppb). Cadmium is slightly more mobile than zinc and zinc can be soluble in the parts per million (ppm) range. Therefore natural adsorption and precipitation of Cd may not be sufficient to stop Cd pollution when Cd is present in waste in large quantities. CdS (greenockite) may be an important precipitate under reducing conditions. However, sulfides in general become more soluble with increasing acidity. Cadmium, like zinc, may be co-precipitated with ferric hydroxide or manganese hydroxide. Co-precipitation with $Fe(OH)_3$ becomes unfavorable under reducing conditions where Fe^{+3} is reduced to Fe^{+2} (since Fe^{+3} is much more insoluble than

Fe^{+2}). Acidic conditions also are unfavorable for ferric hydroxide formation. Therefore, based on both solubility and ion exchange characteristics, maintaining an alkaline pH is critical to immobilize Cd. Because Cd is toxic at low concentrations, controlling hazards from Cd is particularly significant. Cd may accumulate in plants (Leeper, 1978) and then be ingested by humans where it accumulates in the bones (Friberg, et al., 1971). Under most conditions for shallow-land burial sites, Cadmium is probably the most mobile of the six metals discussed in these examples. Cadmium, however, is not expected to be disposed of in large quantities. Cadmium is commonly used to shield test samples from thermal neutrons in activation studies and this, therefore, would become a potential waste source.

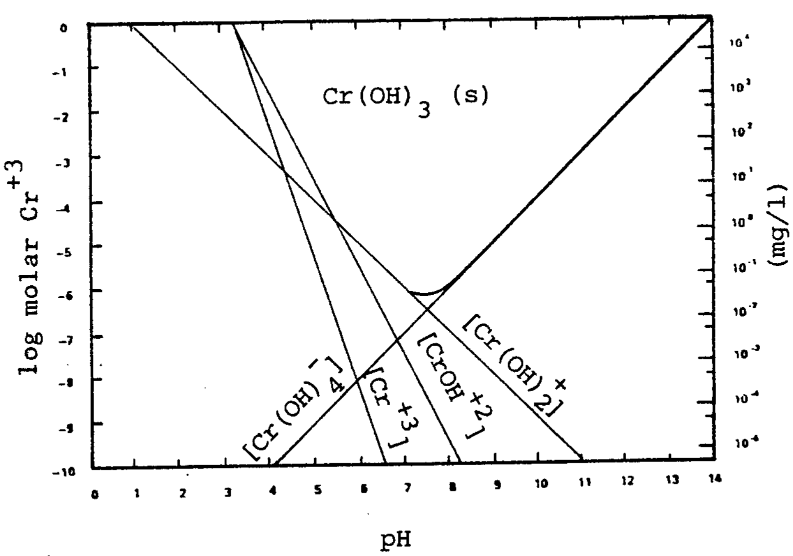
Chromium

Chromium in soil is generally oxidized or reduced to Cr^{+3} and precipitated as an insoluble hydroxide. Cr^{+3} not deposited as hydroxide would be strongly bound by ion-exchange due to its plus three charge. Cr^{+3} forms a soluble hydroxide complex under acidic conditions (Figure 5-7, Jan and Young, 1978). The insoluble hydroxide will maintain Cr^{+3} concentrations below 1 ppm between approximately pH 5.5 and pH 10. Cr^{+3} solubility increases rapidly below pH 5.5.

According to Leeper (1978) hexavalent chromium (Cr^{+6}) is quickly reduced to Cr^{+3} in soil. However, reduction does not always occur (Robertson and Barraclough, 1973) and Cr^{+6} is quite mobile as well as substantially more toxic than Cr^{+3}. In the study reported by Robertson and Barraclough Cr^{+6} was not reduced significantly to Cr^{+3} even though a period of over ten years had elapsed since the hexavalent form first entered the water table. Because Cr^{+6} is substantially more mobile, more soluble and more toxic than Cr^{+3}, it is important that Cr^{+6} is not the form of chromium deposited in a waste disposal site. If Cr remains in the trivalent oxidation state it is much less

FIGURE 5-7

Predicted log molar concentrations of four major species of dissolved Cr^{+3} in equilibrium with solid $Cr(OH_3)$ as a function of pH. A temperature of 25°C and an ionic strength of 10^{-2}M are assumed. The line enveloping the area indicates the predicted total soluble Cr as (Cr^{+3}) + $(CrOH^{+2})$ + $(Cr(OH)_2^+$ + $(Cr(OH_4)^-)$. Jan and Young (1978)



hazardous. A mild reducing environment and a pH of 7-8 are most favorable for removing Cr from water.

Copper

Copper is very insoluble under alkaline conditions and becomes rapidly more soluble at a pH's less than 6 (Figure 5-8, Higgins, 1979). CuO is very insoluble when the pH exceeds 7, and malachite $Cu_2(OH)_2\ CO_3$, forms under slightly acidic conditions. Copper is strongly bound to organic matter and may also be strongly attached to ferric hydroxide precipitate (Leeper, 1978). Under reducing conditions CuS-covellite and Cu_2S-chalcocite are insoluble phases. Copper usually is relatively immobile under neutral or alkaline concentrations (Fuller et al., 1979). Copper can be toxic to plants at high concentrations but is rarely hazardous to humans except when direct leaching of copper from copper plumbing by acidic water occurs. Generally copper is removed to very low concentrations (below 1 ppm) by precipitation as long as the pH remains greater than 6.0.

Lead

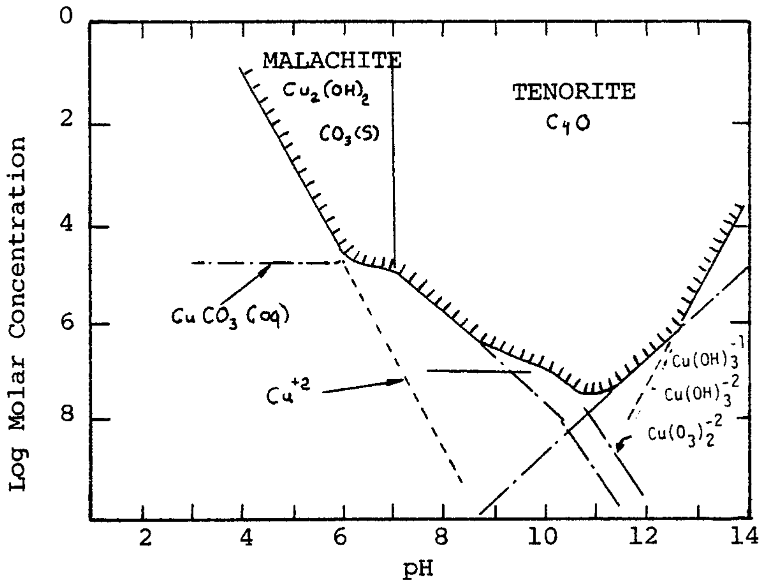
Lead tends to accumulate in the upper layer of soil but is so insoluble that it is usually strongly excluded by plants (Leeper, 1978 and National Research Council, 1972). $PbCO_3$ and $Pb_3(PO_4)_2$ are precipitates which limit the solubility of lead in soil. Under reducing conditions PbS is a precipitate with very low solubility. Pb is strongly bound to humus in soil. According to Leeper (1978) Pb is so strongly bound to clay minerals by ion exchange processes that a strong acid is necessary to remove it from the clays for analysis. Although Pb is a major airborne pollutant, Pb is rarely considered hazardous in soil.

Stumm and Morgan (1970) have evaluated pertinent reactions of lead-water and lead-water-carbonate systems and have constructed equilibruim models to predict the aqueous solubility of lead and lead chemical species. From their evaluation, lead can be

FIGURE 5-8

Solubility of Copper (II) with 10^{-2} Molar Total Carbonate

Stumm and Morgan (1970).



readily dissolved under low pH (acidic conditions) in an aqueous media. Lead dioxide precipitates are formed from Pb^{++} ions in solution under neutral or alkaline conditions, and Pb^{++} is stable in the solid phase as lead oxide. Also lead (IV) oxide is stable in a solid phase under neutral or alkaline conditions, but is unstable under acid conditions. In evaluating the lead-water-carbonate system, the chemistry of solvated Pb^{++} is strongly influenced by the presence of carbonate ions with a decrease in lead concentration corresponding to an increase in carbonate concentration. In addition, the solubility of lead is decreased under alkaline conditions by ions such as chloride, sulfate, and phosphate, but there are also possible soluble complexes of lead consisting of tetradentate and hexadentate ligands. The solution chemistry of lead can be complex depending on the ions present and the pH. In general, the various forms of lead show decreasing solubility under neutral or alkaline conditions, and lead can exist as a variety of salts in the solid phase. Only under acid conditions or at high concentrations at the disposal site is lead likely to be a hazard in run-off.

Zinc

Zinc is strongly precipitated under alkaline conditions (pH 7-12) as hydrozincite (Figure 5-9, derived from Stumm and Morgan, 1970). $Zn_3(PO_4)_2$ is also a phase of very low solubility. According to Jenne (1968) and Walsh, Sumner and Corey (1977) the co-precipitation of zinc with ferric hydroxide is an important process in the removal of zinc from solution:

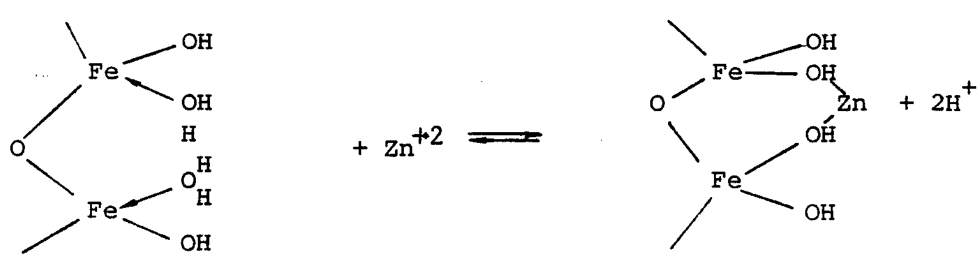
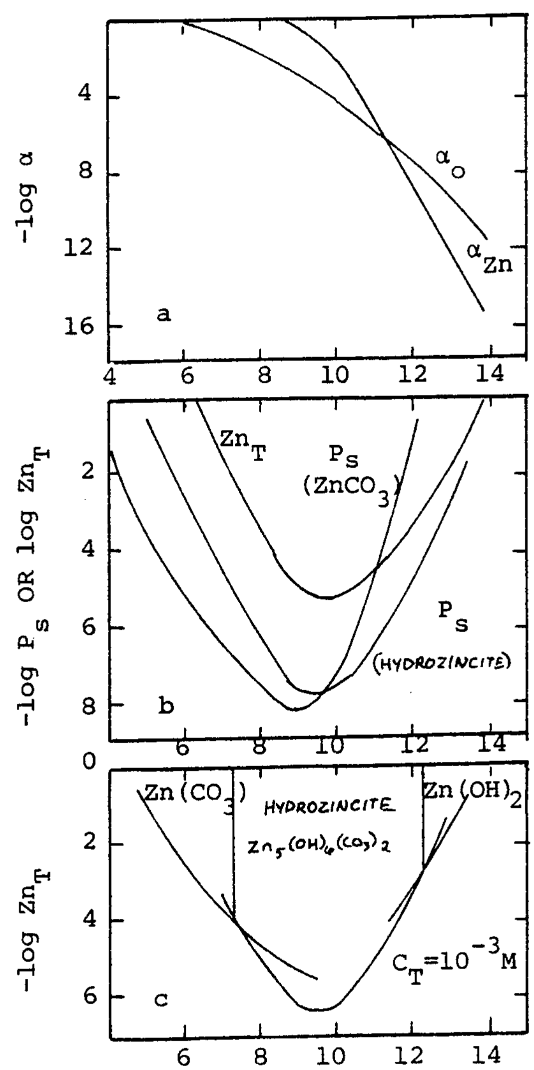


FIGURE 5-9

Conditional Solubility Products of $ZnCO_3(s)$ and Hydrozincite ($Zn_5(OH)_6(CO_3)_2(s)$). (a) a_{Zn} and a_0 versus pH. (b) The conditional solubility products and largest possible Zn_T. (c) Maximum soluble Zn_T in closed system ($C_T = 10^{-3}$M).



However, Leeper (1978) doubts the importance of co-precipitation with iron hydroxide in absorbing substantial concentrations of zinc. If zinc is bound with ferric hydroxide, then reducing conditions would favor its return into water and oxidizing conditions would favor its removal. Under reducing conditions ZnS-sphalerite is a stable phase with extremely low solubility at neutral pH. Acidic conditions favor the solubility of zinc minerals and also greatly decrease the adsorption of zinc by ion exchange. Therefore maintaining a pH of 7.0 or greater will greatly decrease the mobility of zinc and increase its removal from solution.

5.2.2 Organics

The organic compounds selected as representative toxic chemicals cover a wide range of compound types, and so differ considerably in characteristics of environmental concern. The most important processes are adsorption to soil or soil-material surfaces, chemical degradation, and biological degradation. Many other factors and processes influence these key processes.

An initial factor to consider is the likely distribution of the organic compound between phases. A few compounds released subsequent to waste disposal will be slightly volatile (e.g., toluene). Under appropriate conditions such materials may move through an unsaturated zone above the water table and escape, in the vapor phase, into the atmosphere.

Another important characteristic is the water solubility of organic leachates. If soluble, a leachate will be more mobile and may come into contact with more of the environment. For example, in some cases solubility correlates inversely with bioaccumulation, presumably reflecting a contrast of lipophilic and hydrophilic molecular properties. Complex formation may in some instances enhance solubility and subsequent transport and degradation. This could result in greater dilution of a leachate and increase the probability that biodegradation would

be promoted. Dilution could also decrease toxic effects resulting from high concentrations of the materials.

5.2.2.1 Adsorption of Organics

Just as with metals, organic compounds interact in many ways with soil surfaces. Perhaps the most important soil region for study in relation to organics is the "A horizon". This horizon consists typically of clay minerals with a maximum organic matter content forming a "clay-organic complex" (National Research Council, 1977). Within this upper zone of the soil, metal oxides, hydrous metal oxides, and soil organic material (humus) are typically in intimate contact with each other. The hydrous oxides provide even more sites for adsorption of organic matter in soil than do the micaceous clay minerals. Organic polyelectrolytes provide a significant portion of the ion exchange capacity of soils.

Humus has traditionally been fractionated into three components: Humic acid, fulvic acid, and humin. Humic acid is the component soluble in a strong base but not in strong acid; fulvic acid is soluble in both; and humin is soluble in neither. Both soluble and insoluble organic compounds may be sorbed by humus. Humic acids are generally considered to arise form the microbial degradation of organic debris. Some soil fungi can convert a wide variety of organic substrates into phenolic and quinoid compounds and aromatic acids, which then are converted into humic acids.

There is little in the way of actual data relating to adsorption of organic compounds in soils. Some recent studies have been performed as part of an evaluation of pilot wastewater reuse programs (Roberts, et al., 1978). Data for four organic compounds illustrate phenomena which can influence transport processes (Figure 5-10). Chlorobenzene concentrations observed at a test well site following injection of

wastewater containing organics showed a transport curve with the same shape as for injected water itself. However, there was a significant delay in transport of chlorobenzene when compared with a conservative tracer. Chlorobenzene at 300 hours past injection corresponded to water at 11 hours past injection. Dichlorobenzene, presumably more strongly adsorbed, was even slower in reaching the test well site. Trichlorobenezene never appeared at the test well, presumably due to even stronger adsorption. Heptaldehyde also never appeared in test well samples following injection. It was believed to have been removed completely during passage through the aquifer. It should be noted that the more highly chlorinated substances also are less biodegradable (Omiri and Alexander, 1978). Figure 5-11 represents an attempt by these authors (Roberts, et al., 1978) to define retention capacity of soil for an adsorbable organic. Two curves are presented: a very steep curve indicating breakthrough composition for a conservative tracer in water, and a more gently rising curve for chlorobenzene. The difference between these curves (the shaded area in the diagram) is a measure of chlorbenzene retained within the aquifer system.

5.2.2.2 Chemical Degradation

Organic compounds can undergo degradation by a variety of chemical processes. Among these processes, hydrolysis is particularly important. The presence of water also enhances the likelihood of product migration. Hydrolytic reactions are influenced by pH, by temperature and by the presence of other molecular species which may function as catalysts. Compounds likely to undergo hydrolysis include esters, amides, and compounds with leaving groups at positions that would stabilize a carbonium ion (benzylic etc.)

Oxidation-reduction reactions also may occur. Where oxygen is absent or limited, as

FIGURE 5-10

Breakthrough Curves for Trace Organic Compounds at Test Well, Wastewater Injection. Roberts et al (1978)

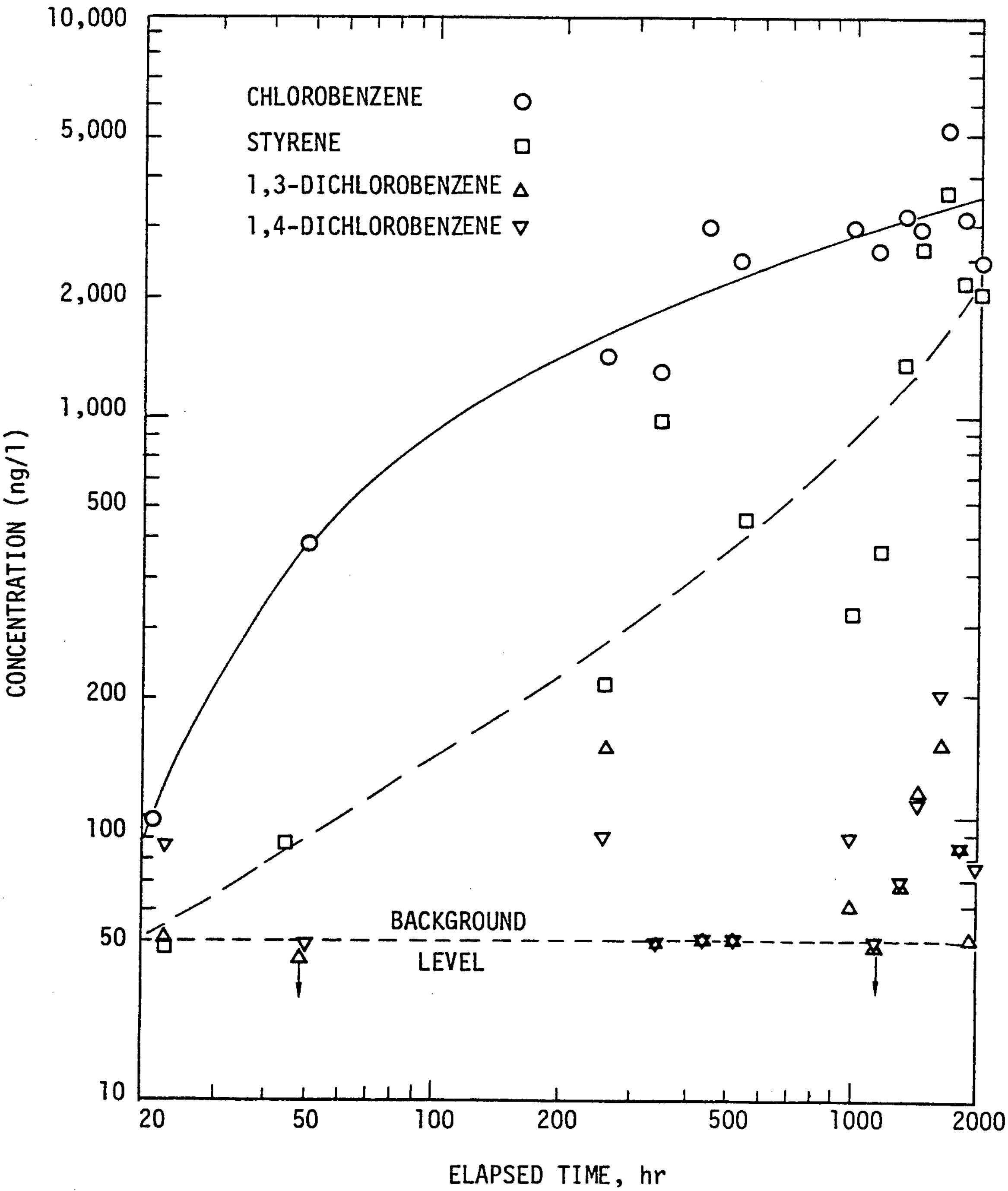
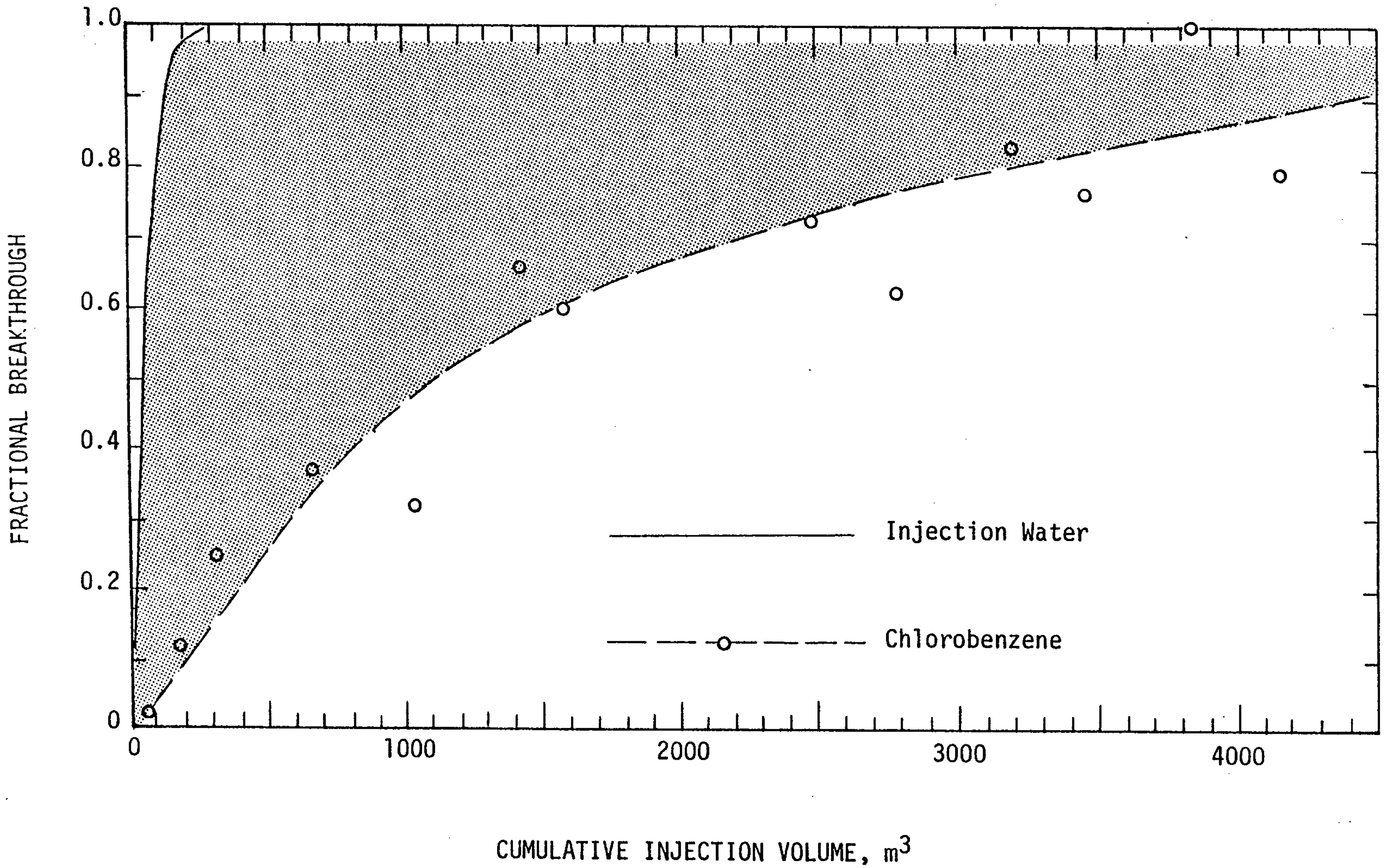


FIGURE 5-11

Estimation of Chlorobenzene Removal Capacity of an Aquifer. (Area between curves measures chlorobenzene removed.) Roberts et al (1978)



would be the case for relatively deep aquifers, anaerobic conditions may facilitate reduction reactions. These reactions also may be influenced by pH, temperature, and the presence of catalysts.

5.2.2.3 Biodegradation

Soil microorganisms must obtain sources of carbon, energy, and essential elements from their environment if they are to survive. Organics can fulfill this requirement. Factors which influence microbial growth from available organic matter include population ecology of the microbe, temperature, soil moisture, pH, redox potential, other nutrient concentrations and availability. Biochemical reactions which degrade organics can encompass oxidation, cleavage of an ether linkage, ring hydroxylation, ring cleavage, ester hydrolysis, dehalogenation, and N-dealkylation. Chemical structure, nature and position of substituting groups affect the extent and rate of microbial degradation of chemicals.

In considering any biochemical activity in the soil, the absolutely essential role of enzymes is fundamental. A general classification of enzymes in soil chemistry is as follows:

1. Oxidoreductase - Enzymes involved in oxidation and reduction reactions.
2. Transferase - Enzymes that catalyze the transfer of a functional group.
3. Hydrolases - Enzymes that facilitate hydrolysis reactions.
4. Lyases - Enzymes that catalyze decomposition of substrates.
5. Isomerases - Enzymes that catalyze changes in shape but not composition.
6. Ligases (synthetases) - Enzymes that catalyze combinations of substrates.

The ubiquity of soil microflora only magnifies the complexity of identifying individual enzymatic reactions in particular

substrates. Section 5.2.2.4 will present specific examples of soil bacteria that were studied in relation to the degradation of the example compounds. Knowledge of microbial degradation mechanisms for specific organics, especially for the host of new chemicals passing into the environment, is very preliminary. Thus, the present approach is still fragmentary and deductive.

However, general rules for biodegradation can be derived as follows:

- Short chain aliphatic hydrocarbons are not as readily attacked as those of higher molecular weight.
- Unsaturated aliphatics are more readily attacked than saturates.
- Branched compounds are relatively more resistant than straight chains.
- Meta-substituted compounds are more resistant than ortho- or para-.
- More chlorine substitutions mean more resistance.

It is also crucial to recognize the non-specific activity of numerous exoenzymes released by microbial organisms, acting to degrade compounds to more useful metabolites.

5.2.2.4 Processes Important to Individual Organic Compounds

Discussion relevant to the transport and fate of individual organic compounds is presented below. From the concentrations of these compounds found in trench waters at Maxey Flats (see Chapter 3, Table 3-4), no adverse effects from these chemicals in or around a burial site can be expected.

1,4-Dioxane

This compound is representative of a group of ethers. Most ethers are immiscible in water; however, dioxane is miscible in all proportions. It is a fairly volatile liquid with a vapor pressure of about 30 mm at 25°C. It has a low partition coefficient of 0.38 and is not thought to have high bioaccumulative properties.

Chemically ethers are fairly inert, however they do have a tendency in the presence of sunlight and moisture to form hyperperoxides and peroxides (Allinger, 1971). Chemical studies have indicated possible cleavage of the CO bond, with an acid as the catalyst, resulting either in an alcohol or alkyl groups.

No direct literature references on the biodegradation of dioxane by any particular microflora were found. Its low lipophilicity and rapid metabolism in mammals suggest that dioxane is biodegradable. Degradation of dioxane in the soil is probably initiated through its chemical conversion to peroxide.

Oxalic Acid

Oxalic acid is a colorless, non-volatile, water soluble liquid. Chemical decomposition of oxalic acid involves decarboxylation to carbon dioxide and formic acid.

If it were not for the utilization of oxalate by microbes for energy, it could be assumed that oxalic acid would travel very far through soil. However, oxalate is a direct metabolite of microbial respiration (Higgins, 1975) and of anaerobic respiration by methanol-oxidizing bacteria (Kuhn, 1978). All strains of the latter were found to utilize oxalate to 99.9 percent degradation in 5 days.

Diacetone Alcohol

This compound belongs to the group of alcohols, and shows most of the chemical properties of alcohols. In addition, it takes part in reactions involving the keto group. It is stable in the pure state, but decomposes rapidly in alkaline or acidic media, such as soil fractions of fulvic acids, to form a decomposition product which is mostly acetone.

Diacetone alcchol is miscible in water and dissolves readily in alcohol and ethers. It has a low molecular weight (116.1) and vapor pressure (1.1 atm at 20°C), which would make

it a mobile compound through wet soils, if it were not for chemical and biochemical interactions.

Acetone has been identified as the sole carbon source for a number of nonsulfur purple bacteria, the most significant of these being Rhodopseudomonas gelatinosa (Siegel, 1950). It is postulated that acetone condenses with CO_2 to form acetoacetate and is further incorporated into cell material, as shown below (Doelle, 1975).

$$
\begin{array}{lllllll}
\text{acetone} & \rightarrow & \text{acetoacetate} & \rightarrow & \text{acetate} & \rightarrow & \text{cell material} \\
\downarrow & & & & & & \\
\text{acetol} & \rightarrow & \text{methylglyoxal} & \rightarrow & \text{pyruvate} & \rightarrow & \text{cell material} \\
\downarrow & & & & \uparrow & & \\
\text{dihydroxyacetone} & \rightarrow & \text{glyceraldehyde} & & & &
\end{array}
$$

<u>1, 1, 1-Trichloroethane (Methyl Chloroform, TCE)</u>

This compound is an insoluble, halogenated hydrocarbon with a high partition coefficient (93.9). It is a volatile liquid with a vapor pressure of 100 mm at 20°C. Evaporation rates have been calculated to indicate a 50 percent loss at 25°C from a 1 ppm solution in 20 minutes.

There was no literature found on any biodegradation studies of trichloroethane. It is postulated from generic studies of halogenated organics and soil interactions (Rogers, 1979) that trichloroethane falls under the category of those compounds that will most resist biodegradation. However, biodegradation cannot be completely ruled out since there are several dehalogenating bacterial species (Pseudomonas sp.) in soil. However, the process would be very slow and studies indicate that the initial metabolite for these dehalogenating bacteria would most likely be a halogenated acid (Omiri, 1978).

Therefore, because of its insolubility in water, slow biodegradation and high vapor pressure, TCE would tend to be removed from a site by volatilization.

1-Octanol

Octanol is a common solvent utilized in the manufacture of plasticizers and foam controlling agents, with several possible modes of release into the environment. It has large partition coefficient (1412.5)and so is only slightly soluble in water. This characteristic is likely to impart a high potential for biomagnification of octanol (Verschueren, 1977). Mobility of n-octanol in the terrestrial environment is facilitated by its low molecular weight and relatively linear configuration. Also, the compound's mobility in any environment possessing solvents and oils is helped by its ready solubility in alcohols and ethers. It is not a volatile substance, having a low vapor pressure of 1 mm at 20°C.

Extensive studies have been performed on microbial degradation of such aliphatic hydrocarbons (Klug, 1971). The general model for attack by bacterial populations involves oxidation of an alcohol to the related carboxilic acid from which the compound is systematically broken down via b-oxidation and decarboxylation to pyruvate and acetyl fractions. These final metabolites are then directly incorporated into the energy production cycles of the bacteria with ultimate excretion of CO_2 and H_2O. For example, in Pseudomonas oxaliticus (Hopner, 1971):

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CHOH$ (octanol)

$\downarrow$ **oxygenase**

$CH_3(CH_2)_6COOH$

$\downarrow$ **B-oxidation**

$CH_3(CH_2)_4CHOH + CH_3COOH$

$\downarrow$ **B-oxidation (repeated)**

$CH_3(CH_2)_2CHOH + CH_3COOH$

$\downarrow$

Acetyl COH

$\downarrow$

Krebs Cycle

$\downarrow$

$CO_2 + H_2O$

1, 1-Diethoxyethane (Acetal)

This is a fairly volatile diethylether which is soluble in water and many organic solvents. One of the initial chemical/transformations of this unstable compound is to acetone. This may occur in the presence of light or in moist environments. As with many other ethers, it has a strong tendency to form hyperperoxides. These may further autooxidize to release hydrogen peroxide, aldehyde and glycol. Steps may be as shown below (Kirk, Othmer, 1963):

$$C_2H_5 - O - C_2H_2 - O - C_2H_5$$

$$\downarrow \quad \text{photooxidation or wet oxidation}$$

$$CH_3 - \underset{|\atop OOH}{CHO} - C_2H_5 - CHO - \underset{|\atop OOH}{C_2H_5}$$

$$\downarrow \quad \text{autooxidation}$$

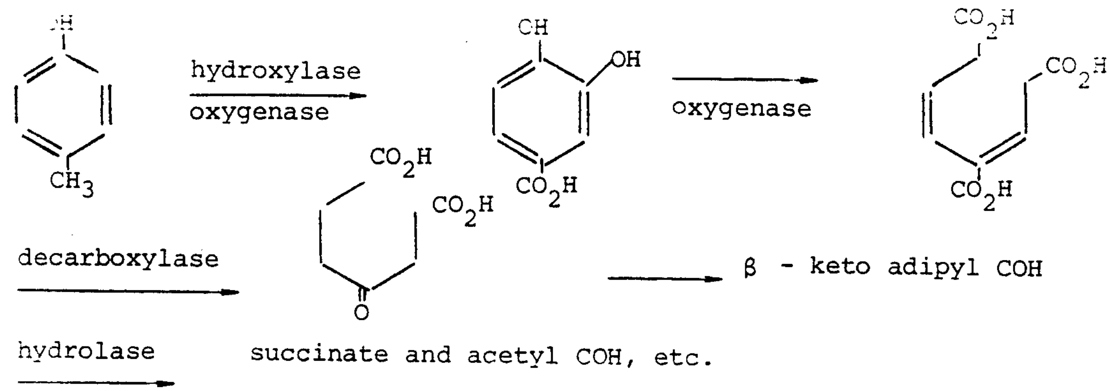
$$2\ CH_3CHO + 2\ H_2O_2 + (CH_2OH)_2$$

The reactions shown above are spontaneous, and it is postulated that microbial degradation of either the acetone or the aldehyde and glycol products of autooxidation is fairly straight forward. Metabolism of acetone by anthiorodaceae is already known (Siegel, 1950) and incorporation of glycol and aldehydes into various bacterial metabolic pathways is substantiated in numerous studies (Doelle, 1975).

Cresols

These are members of a widely distributed class of phenolic compounds and are constituents of most natural runoffs. They are byproducts from wood and coal tar processing, and are used in products ranging from disinfectants to surfactants. They are mildly acidic, soluble in water, and readily engage in ester formation with weak acids such as those in soil. Cresols are fairly non-volatile with vapor pressure of around 0.20 mm at 25°C. It might anticipated that cresols would be mobile in moist soils due to their solubility and acidic

interactions. However, studies also have noted their ready degradation by bio-organisms leading to their incorporation in processes that release energy for microbial growth (Dagley, 1971). This is exemplified with Pseudomonas testosteroni and p-cresol.



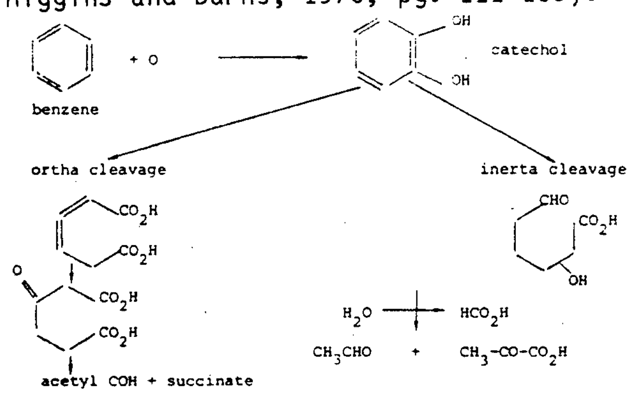
Thus, cresols are rendered biodegradable and an estimate of 1 day for complete decomposition by microflora has been recorded (Alexander, 1966).

Toluene

Toluene is found naturally in petroleum and coal tars and is widely used in the manufacture of various benezene derivatives. It is an aromatic hydrocarbon exhibiting most of the chemical properties of benzene. It is a fairly volatile, colorless liquid with a vapor pressure of around 22 mm at 20°C. The compound is only slightly soluble in water, but readily dissolves in most organic solvents. Chemical reactions of toluene can be schematically represented as shown below (Kirk, Othmer, 1963).

Toluene
- → Dealkylation → Benzene
- → Oxidation → Benzoic Acid
  - → Phenol
  - → Terephthalic acid
  - → Caprolactam
- → Nitration
- → Chlorination
  - → Ring chlorination → Dyes
  - → methylgroup → Plastics
- → Sulfonation → Toluene sulfonic acids
- → Alkylation → Alkylated toluene intermediates

Biodegradation of toluene has been known since 1908, but it has been only recently that the various schemes of degradation have been studied along with intermediates. Microbial oxidation of toluene has been best exemplified by Pseudomonas sp. as shown by the following oxidative process for benezene (Higgins and Burns, 1975, pg. 111-139).



An alternative pathway, also very likely, would be the transformation of toluene to benzoic acid with catechol formation, again to follow the scheme shown above.

Various studies of oil-polluted soil have indicated a ready degradation of toluene to CO_2 and H_2O (Walker, 1967).

Di-2-Ethylhexyl Phathalate

Phthalate esters, of which the subject compound is an example, are now widely distributed through the environment because of their large scale use as plasticizers and the opportunities for loss. This compound is characterized by very limited water solubility, and moderate solubility in alcohols and organic solvents. Vapor pressure is moderately high. It is metabolized fairly easily and rapidly by various species at the higher end of the food chain, and biodegraded slowly by lower level organisms. Metabolics are the monoester and alcohol. The compound has a relatively low toxicity.

No data are known to have been developed on the actual adsorption of phthalate esters on soil or soil constituents. However, its

properties are such that one would expect sorption to occur, particularly to organic matter. Studies by Autian (1973) and Peakall (1975) indicate that phthalate esters are readily adsorbed onto suspended solids and particulate matter in aquatic environments. Because phthalate esters are found in sediment samples from streams bottoms, etc., (Giam, et al., 1978), the studies by Autian (1973) and Peakall (1975) appear to be confirmed.

Mobility of phthalate esters in the terrestrial system is likely to be aided by the formation of highly water soluble complexes with fulvic acids present in the humic substances of waste soil (Autian, 1973; Ogner and Schnitzer, 1970). Mobility of phthalate esters from landfills also may be enhanced by solvents and oils in the refuse.

The phthalate esters have been noted as having a low vapor pressure. Thus volatilization would not appear to be an important transport mechanism. However, since plasticizers are often used in large protortions within plastics, and since landfills may include temperature and pressure increases as well as mechanical breakdown, some local transport by volatilization may take place.

Microbial systems are known to be able to degrade phthalate esters (Mathur, 1974a, 1974b). The mechanism probably involves some form of enzymatic oxidation and hydrolysis, with a faster rate under aerobic than anaerobic conditions. The degradation rate also depends on temperature, pH, and other variables. Serratia marcescens was able to utilize bis (2-ethyl-hexyl) phthalate as a sole source of carbon and energy at substrate levels up to 2.5 percent (Mathur and Rouatt, 1975). In fresh water hydrosoil in the laboratory, di-n-butyl phthalate was degraded with a half-life of about one day under aerobic conditions, 98 percent was degraded within five days (Johnson and Lulves, 1975). Hydrolysis to a monoester and alcohol

were found, followed by probable decarboxylation of the available carboxyl groups leading to 1, 2-dihydroxybenzene. Best conditions were at pH 7 to 9, and 20°C.

No specific information was found on hydrolysis under conditions applicable to leachate from landfills. Most likely, the half-life would be very long in comparison to biodegradation processes.

5.3 Summary Assessment Tables

The probable natural degradation removal processes of importance are provided as a summary assessment in Tables 5-3 (inorganic) and 5-4 (organic).

5.3.1 Inorganic Compounds

Many specific degradation processes (entered in Table 5-3 for completeness) are not applicable to inorganics or are of no real importance; thus "NA" is entered. Where entries are made, they represent estimated rankings within the classification. Thus, cadmium is estimated to be the least strongly adsorbed on soil particles, and so ranked 6th of 6. Chromium and lead appear tied for the most strongly adsorbed, and so ranked 1-2. Other usages are similar.

Key concerns are the mobility and lifetime of the compounds. For inorganics, lifetime is not really an issue since the metals of concern are always "there"; a change in chemical form or other change may be needed to make them available in some cases, but the metal will be observed in leachate, groundwater or on the soil. Thus, the measure of true concern is the overall estimate of the metal's mobility in the expected environment. The three elements of greatest concern (in rank order) appear to be cadmium, copper and chromium.

5.3.2 Organic Compounds

For the organics, presented in Table 5-4, the data again indicate some degradation and removal that are not applicable. Compounds in the table do not represent rankings because analysis depends on judgement rather than well defined data.

Factors that appear to be most important are mobility and persistence and in this instance entries can be made for each. Concern is greatest for the highly mobile compounds, with long expected lifetimes. No extremes are present. Compounds near the top of the list might be 1,1,1-trichloroethane (for its probable long life), 1,4-dioxane (for its mobility and probable moderate life), and toluene (for its moderate mobility and persistence).

It appears fortunate that many of the compounds that are potentially of great concern due to their toxicity seem certain to disappear rather quickly under most natural conditions. A word of caution is in order, however. The data base for the transport and fate of waste constituents is too limited for properly conducting a comprehensive assessment. Substantial research is necessary before solid data will underlie good estimates of transport and fate.

TABLE 5-3

Natural Degradation/Removal Processes: Ranking of Inorganics

Processes →	Soil Adsorption	Chemical Degradation	Photochemical Reactions	Thermal Degradation	Bio-Degradation	Chemical Complexation
Representative Compounds						
Barium	4	NA	NA	NA	NA	6
Cadmium	6	NA	NA	NA	NA	4
Chromium	1-2	NA	NA	NA	NA	2
Copper	3	NA	NA	NA	NA	1
Lead	1-2	NA	NA	NA	NA	5
Zinc	5	NA	NA	NA	NA	3
Processes →	**Ion Exchange**	**Precipitation**	**Filtration**	**Volatilization**	**Mobility**	**Persistence**
Representative Compounds						
Barium	4	1-3	1-3	NA	4-6	NA
Cadmium	6	6	6	NA	1	NA
Chromium	1-2	1-3	1-3	NA	3	NA
Copper	3	4	4	NA	2	NA
Lead	1-2	1-3	1-3	NA	4-6	NA
Zinc	5	5	5	NA	4-6	NA

Key:

TABLE 5-4

Natural Degradation/Removal Processes: Ranking of Organics

Processes →	Soil Adsorption	Chemical Degradation	Photochemical Reactions	Thermal Degradation	Bio-Degradation	Chemical Complexation
Representative Compounds						
1,4-Dioxane	Moderate	No	No	No	Moderate	No
Oxalic Acid	Moderate	No	No	No	Rapid	No
Diacetone Alcohol	Moderate	Yes	Yes	No	Rapid	No
1,1,1-Tri chloroethane	High	No	No	No	Slow	No
1-Octanol	Moderate	No	No	No	Rapid	No
1,1-Diethoxy-ethanol	Moderate	Yes	Yes	No	Rapid	No
Cresols (o,m,p)	High	No	Yes	No	Rapid	No
Toluene	Moderate	No	Yes	No	Rapid	No
Di-2-ethylhexyl Phthalate	High	No	No	No	Rapid	Yes

Processes →	Ion Exchange	Precipitation	Filtration	Volatilization	Mobility	Lifetime
Representative Compounds						
1,4-Dioxane	NA	NA	NA	Moderate	High	Moderate
Oxalic Acid	NA	YES	YES	NO	Moderate	Moderate
Diacetone Alcohol	NA	NA	NA	Moderate	High	Short
1,1,1-Tri-Chloroethane	NA	NA	NA	High	Moderate	Long
1-Octanol	NA	NA	NA	No	Moderate	Short
1,1-Diethoxy-ethanol	NA	NA	NA	Moderate	High	Short
Cresols (o,m,p)	NA	NA	NA	No	High	Short
Toluene	NA	NA	NA	Moderate	Moderate	Moderate
Di-2-ethylhexyl Phthalate	NA	NA	NA	No	Moderate	Short

6.0 RELATIVE HAZARDS OF TOXIC CHEMICALS AND LOW-LEVEL RADIOACTIVE WASTES

6.1 Relative Hazard Evaluations

Hazard evaluations for toxic chemicals and low-level radioactive wastes have generally been performed independently without a means of comparing one type of hazard with another. This has been the case because exposure of biological systems to ionizing radiation results in non-specific damage, while exposure of biological systems to a chemical can produce specific damage related to a molecular structure and specific biological activity. Consequently, comparison of radioactive hazards with chemical hazards is difficult because there are differences in the underlying mechanisms of action for radiation effects compared to chemical effects. Since it is difficult to describe the hazards of chemicals and radiation in commensurate terms, a relative comparison of hazards appears to be an appropriate approach.

In developing a relative comparison, the degree of hazard from a particular agent depends on the exposure conditions, the host or target system, and the intrinsic toxicity of the particular agent, either radiologic or chemical. Toxicity can be regarded as the capacity of an agent to cause harm or to produce adverse effects. Both low-level radioactive wastes and chemical wastes can be accommodated by this general definition of toxicity.

In hazard evaluations, the potency of the agent, severity of potential adverse effects, volume and distribution concentration or intensity in the system, route of exposure, duration of exposure, and the degree of susceptibility of the host, target population, or system at risk are essential factors in defining the degree of hazard from exposure to a particular agent. Except for the potency of the agent and the severity of potential adverse effects, all other factors in evaluating the degree of hazard are related to specific site characteristics and management practices.

Essentially, a relative hazard evaluation for comparing low-level radioactive wastes with chemical wastes evolves into three distinct operations.

1. Independently rank the hazards of low-level radioactive wastes.

2. Independently rank the hazards of chemical wastes.

3. Develop a common scale or define discrete hazard categories making use of the independent hazard rankings.

Although no satisfactory method for comparing hazards of radioactive agents and chemical agents is currently available, these operations define a strategy for developing a methodology to make such comparisons. Development of such a comparative or relative hazard approach is beyond the scope of this report. However, there are numerous approaches described in the literature that might be applicable to developing an assessment of relative hazards from either chemicals or low-level wastes. A bibliography identifying significant publications of interest related to hazard assessments is included as Appendix H. The listed publications cover application of decision theory, risk-cost-benefits analysis, dose-response relationships, and a variety of approaches to assessing risks and hazards for either chemicals or low-level radioactive wastes. There is no approach described that allows a comparison of relative hazards between chemicals and radioactive wastes, but a starting point to develop such an approach would be by reference to the bibliography in Appendix H.

In the following sections, methodologies for ranking of hazards, radiological hazard evaluations, chemical hazard evaluations, and relative hazard rankings are presented.

6.2 Methodologies for Hazard Ranking

There are four hazard assessment methodologies that could be applied to evaluating chemical and low-level

radiation hazards, and developing a relative hazard ranking for both. These are:

1. Expert-based approach, where experts assign actual priorities, based on informed judgement or opinion.

2. Categorization approach, where chemicals or low-level wastes are grouped into several predefined, ranked categories based on specific physical, chemical, or biological properties (e.g., structural similarities).

3. Index approach, where numerical scores are assigned to a series of factors, which are combined (utilizing suitable weighting factors)to produce a single score for a particular chemical or low-level waste.

4. Model approach, where compartmental and mathematical models are constructed to define those processes causing an agent to show toxicity or to represent a hazard.

Table 6-1 indicates the advantages and disadvantages of the various methodologies.

The expert-based approach is most easily implemented and economical in the short-term but it is potentially more subjective than other models. Also, there is greater difficulty in maintaining consistency of evaluations over extended time periods because social value judgments and technological understanding of issues will necessarily change. An example of an expert-based system is the Threshold Limit Values approach of the American Conference of Governmental Industrial Hygienists. This and other approaches will be discussed in later sections. The expert-based approach has been the predominant approach used in hazard evaluations.

Categorization is a technique that has been used to characterize hazards. Its relevance depends on the criteria used to define explicit categories. Given that the assumptions used to establish the categories are valid statements representing the degree of hazard, this approach is easily implemented. However, there is limited flexibility and the rankings and assignments to categories can be subjective.

TABLE 6-1 ADVANTAGES AND DISADVANTAGES OF METHODOLOGIES FOR HAZARD EVALUATIONS

Approach	Advantages	Disadvantages
Expert-Based	Easily implemented	Dependent on capability/ credibility of experts
	Relatively inexpensive	
	Can be simple and systematic	Necessarily subjective Ranking consistency over a period of time difficult to maintian
	Use of recognized experts lends credence to assessment.	
Categorization	Easily implemented	Limited flexibility
	Explicit statement of categories/assumptions	Subjectivity often involved
Index	Flexible approach	Subjectivity often involved
	Simple/easily implemented	Data limitations often require projections assumptions
	Explicit statement of assumptions	
Model-Based	Relatively objective	Least feasible technically, economically
	Explicit	
	Credible	Complex, difficult to understand
	Highly related to specific hazards	Imposes substantial data requirements

Indexing can be a flexible approach based on an explicit statement of assumptions. However, there may be considerable uncertainty due to lack of adequate data to make projections or assumptions. Consequently, indexing can be subjective. An indexing approach for evaluation of hazards is presented in the section on chemical hazard evaluation.

A model-based approach can be explicit and relatively objective in ranking hazards. However, there are substantial data requirements, and the results can be highly related to the data set available. When adequate data are available, a model-based system provides explicit and credible results. But a model is often complex, difficult to understand, and costly to implement.

Essentially, the methodology of choice for hazard ranking is predominantly an expert-based approach supported by use of categorizing, indexing, and modeling depending on data available, resources, and extent of hazard definition desired.

6.3 Radiological Hazard Evaluation

Current methods for evaluating or assessing the potential hazard or degree of risk from radioactive materials are based either directly or indirectly in ICRP Publication 2, "Report of Committee II on Permissible Dose for Internal Radiation". This report sets forth the Maximum Permissible Body Burdens (MPBB) and the Maximum Permissible Concentrations (MPC) in air and water for most radionuclides. With respect to chemical form, the MPC values are tabulated only for the relatively insoluble compounds and for the more common soluble compounds. These forms are specified only by the extent of solubility (soluble or insoluble) rather than by specific chemical structure. All of the values are specified in terms of a "standard man" and do not take into consideration individual variations or special sub-groups of the population (i.e., children).

The MPC values represent concentrations of radionuclides which, if continuously ingested or inhaled (40 hours a week for occupational exposure or 168 hours a week for non-occupational exposures) will result in a dose rate (e.g., rem/week) that does not exceed some specified value after 50 years of such exposure. The specified value depends upon the organ

in question and upon the exposure status of the individual involved (occupational or non-occupational). The risks associated with the maximum permissible dose values have been discussed and debated extensively in the literature for years. In this report, it is not necessary to precisely quantify the absolute risk, but rather to examine the extent to which the relative risk or relative radio-toxicity is properly rated by the MPC values.

To evaluate the MPC as a measure of relative risk or of radiotoxicity, it is necessary to specify what is and what is not included in the MPC calculations. The lack of chemical specificity, the issues of biologic variability, and use of "standard man" from the calculation have already been discussed. The MPC values are calculated from the following factors:

1. The effective absorbed energy per disintegration of a radionuclide in the organ or interest.

2. The type of radiation in terms of the relative biological effectiveness (now called the quality factor).

3. The physical half-life of the radionuclide involved.

4. The mass of the organ of interest.

5. The fraction of the ingested or inhaled nuclide that reaches the organ of interest.

6. The biological half-life of the deposited material in the organ of interest.

7. Inhalation and absorption.

8. Allowable dose rate.

9. Relative damage factors for bone-seeking radionuclides.

In the list of factors given, items 1, 2, and 3 are usually quite well known (although even the quality factor may not be the simple parameter often implied because it is often based on qualitative value judgement and depends on the selection of the reference

radionuclide). Item 4 is subject to biological variability which may be quite sizable in the case of special population groups. Items 5 and 6 are often subject to considerable uncertainty. The calculations assume a simple compartmental model in which each organ is assigned a biological half-life. The nuclide enters the organ at a constant rate dependent on the rate of inhalation or ingestion, but is eliminated at a rate proportional to the amount of activity in the organ based on the effective half-life concept. In many cases this is undoubtedly a great oversimplification, since animal studies usually indicate elimination, for example, to be best described by multicomponent exponential functions or by power functions. Further, these elimination functions may be quite dependent on the chemical form of the material deposited, the biochemical processes that occur in the organ of interest, and other factors. Nevertheless, in the interest of uniformity and simplicity, the ICRP Tables assume a single compartment model for each organ. In general, no consideration is given to chemical toxicity in determining MPC values. An exception to this is the case of uranium where chemical toxicity is the limiting criterion for the long-lived uranium nuclides. Under items 7, 8, and 9, there is an evaluation of the absorption distribution, and tissue storage characteristics of a substance. Depending on the chemical characteristics, the transport and storage, and elimination of materials can follow a variety of pathways. Fat soluble materials can show a tendency to be retained in slow exchange compartments in the tissues. Water soluble materials are generally distributed in blood and interstitial fluids consisting of a rapid exchange compartment. Water soluble materials show a tendency for more rapid elimination than do less water soluble materials. In certain cases, inorganic substances follow pathways similar to other elements in the same atomic series, and varying degrees of damage may be produced requiring the application of relative damage factors to estimate the MPC. This is particularly the case with bone-seeking radionuclides that mimic calcium pathways.

Other shortcomings in the MPC values are pointed out by the ICRP. These include a recognition that organ distributions in the body following an acute intake of some material may be markedly different from the assumed distributions in ICRP Publication 2 which are based on chronic uptakes. Other factors of importance

include the effect of dietary intake of other compounds with similar chemical properties to the nuclide of interest and the influence of the wide range of physiological differences, habits, nutrition, age, and sex on the parameters upon which the MPC values are based.

In discussing hazard assessment, Cember (1969) points out that the MPC values do not in most instances consider the chemical form of the radionuclide, the influence of the chemical form on the metabolic properties of the nuclide, nor the resulting effect on absorbed dose from such metabolic parameters. Cember provides numerical examples which demonstrate the extent to which consideration of metabolic properties of a compound may alter the assessment of hazard for the radionuclide. Likewise, Feige (1964) has pointed out the significant effects of organ size and nutritional habits on MPC values.

A refinement of the hazard evaluation can be made by applying the MPC concept coupled with a factor which takes into consideration the probability of ingesting or inhaling the material. Thus, for example, a material which might otherwise be considered very radiotoxic in terms of its MPC value, but which, because of its chemical form, physical form, or other factors, has a low probability of entering the body, might in fact be regarded as not being a radiological hazard. This concept has been considered by Morgan et al. (1964) in some detail and has become the basis for developing radiotoxicity categories for laboratory use of radionuclides.

Morgan and his co-workers developed an index for relative hazard, H, for various radionuclides. H was defined as the ratio of the average concentration inhaled (μCi/CM) to the maximum permissible concentration, MPC, of the radionuclide for occupational exposure. This concept follows the general scheme (Morgan et al, 1955) they originally proposed at the first conference on Peaceful Uses of Atomic Energy:

$$H = \frac{P}{MPI}$$

where H is the relative hazard
P is the probability of taking a certain quantity of the nuclide into the body,
and MPI is maximum permissible daily intake (μCi/day).

Morgan et al. (1964) restated their original formulation in the form

$$H = C \times \mathrm{Min}(A \times c/g, 2.9 \times 10^{-10})/(MPC)_c$$

where H is the relative hazard (a dimensionless index),
and C is the activity of the radionuclide (in curies).

The symbol Min(x,y) denotes the smaller x and y and thus is either 2.9×10^{-10} or the product $A \times \frac{c}{g}$ if this product is less than 2.9×10^{-10},

where c/g is the specific activity.

The symbol $(MPC)_c$ is the maximum permissible concentration of the radionuclide in air in microcuries per cubic centimeter. The constant, A, is equal to the dust loading in air ($\mu g/cm^3$) divided by dilution factors as follows:

$$A = \frac{10^{-4}}{(d + 1)(b + 1)}$$

where dust loading is assumed to be constant at 10^{-4} $\mu g/cm^3$, b is the chemical dilution of the radioisotope by stable isotopes or other inert material, and d is the dilution of the radioactive mixture by other airborne dust. The paper by Morgan et al. (1964) gives the complete derivation of the relative hazard formula, including the constants involved. This evaluation of relative hazard pertains to airborne radionuclides in the laboratory.

Thus, it does not pertain directly to the case of radioactive wastes, which are more likely to find their way into the body via water or foodstuffs. Nevertheless, this method of determining relative hazards provides insight into the type of computational methods that might be used to objectively evaluate radiotoxicity. After calculating H, values for an extensive list of nuclides, Morgan et al. (1964) grouped them by H values and compared them to the

relative toxicity categories defined by the IAEA (Safety Series No. 6, 1963; Technical Report Series No. 15, 1963) (Sanitary Regulations, etc., 1961) and by the USSR (8). A fairly wide variation in radiotoxicity classifications between the various groups can be seen. This variation is undoubtedly related to the methodology (or lack thereof) used by various groups in attempting to assess relative hazard.

Other investigators have developed similar relationships for determining relative hazard. Dubamel and Lavie (1959) recommended the following:

$$H = \frac{1}{\sqrt{(MPC)_g \times (MPC)_c}}$$

where $(MPC)_g$ = maximum permissible concentration of material in $\mu g/cm^3$

and $(MPC)_c$ = maximum permissible concentration of material in $\mu Ci/cm^3$

The equation can be written $H = \frac{\sqrt{c/g}}{(MPC)_c}$

where c/g is specific activity of radionuclide.

Although the formulations of Morgan et al. and of Duhamel and Lavie do not apply directly to assessing radioactive waste toxicities in shallow-land-burial sites, the methods of these investigators indicate that additional factors must be considered beyond the simple maximum permissible concentration values. An approach of this type has been applied to environmental releases of radioactivity and might, with suitable modifications, be applicable to an evaluation of the radiotoxicity of low-level waste (or even to the chemical toxicity or a suitable combination of the two). The approach referred to is that of the Cumulative Exposure Index (CUEX), a methodology that has been discussed in a number of recent papers (Kaye, et al. (1971), Rohwer, et al. (1975), Sweeton,(1978), Sears et al. (1975), Pechin et al. (1975), Finney, et al. (1975), Killough and McKay (1979)). A CUEX value may be defined as that integrated concentration of radioactivity in an environmental medium which will result in a total dose commitment to man which is equal to a selected dose limit or standard, Rohwer (1976). In this aproach, all significant modes of exposure to man are considered, including ingestion, inhalation, and even submersion in contaminated air or water. The

basic formulation of CUEX is described by Kaye et al (1971). They have developed a computer program for calculating CUEX values for various modes of exposure. The CUEX method makes use of dosimetry and transport models in what is described as a "collective assessment methodology." A system of models is used to quantitatively describe radionuclide behavior during the time period between environmental input and intake by man. Thus the method actually incorporates an estimation of the probability that a radionuclide released or placed into the environment will actually find its way into man. Such estimates in the model could be based on assumptions (concerning site parameters, meteorology, site specific dietary data, etc.) or on an actual data base for a particular site.

Another method of assessing hazards from radioactive wastes has been proposed by Gera and Jacobs (1972). They introduced the Potential Hazard Index (PHI) which was defined as:

$$PHI_i = P_i \frac{Q_i}{MPI_i} \cdot \frac{\tau i}{0.693}$$

where Q_i is the total activity of the i^{th} nuclide in microcuries, MPI_i is the maximum permissible annual intake of nuclide i in microcuries, τ_i is the physical half-life of nuclide i (in years), 0.693 is the natural log of 2 (i.e., ln 2), and P_i is a factor that depends on the biological availability of radionuclide i once it is released into the environment and on the reliability of waste containment. Accordingly, P_i represents the probability of nuclide i leaving the disposal site and reaching man. A current practical weakness in this formulation is that values of P_i are not known in most, if not all cases. Furthermore, the values for MPI_i are directly related to MPC values and thus suffer the same limitations already ennumerated for MPC's.

The Committee on Radioactive Waste Management of the National Research Council (1978) has reviewed the hazards from high level radioactive wastes at the Hanford Reservation. To assess the potential hazard of radionuclides in a geologic repository, the Committee defines a Radiotoxic Hazard Index (RHI):

$$(RHI)_i = Q_i/(MPC)_w$$

where Q_i is measured in curies of radioactivity of type "i" in the repository, and $(MPC)_w$ is the maximum permissible concentration in water of that radionuclide (expressed in curies per cubic meter). The $(RHI)_i$ value is then expressed in cubic meters of water and is the amount of water required to dilute the radionuclide to the $(MPC)_w$ value. The greater the RHI value, the greater the potential hazard of the nuclide. In calculating RHI values, one must consider the change in Q_i as a function of time due to radioactive decay. This particular treatment assumes that all nuclides in the waste are dissolved instantaneously and does not take into consideration various chemical and physical forms that could drastically alter the leaching rates of materials from a respository.

The hazard scheme used by the National Research Council is similar to that proposed by Bell and Dillon (1971) in evaluating long-term hazards from high level wastes. They proposed measuring the hazards in terms of the volume of water necessary to dilute various types of waste to radiation concentration guides (i.e., essentially the MPC). This method has also been used by Claiborne (1972) in his report on high level waste. Hamstra (1975) also uses this scheme although stated in a slightly different way, namely:

$$(RHM)_i = \frac{Q_i}{(MPC)_i}$$

where (RHM) stands for the term "Relative Hazard Measure," Qi is the radioactivity (in curies) of nuclide i, and $(MPC_w)_i$ is the maximum permissible concentration in drinking water for nuclide i (in curies per cubic meter). For a mixture of radionuclides, Hamstra suggests using the summation, $\sum_{i=1}^{n} (RHM)_i$, which will equal the sum of the volumes of water calculated for each nuclide separately.

In developing safety indices and evaluating their application to nuclear waste management, Voss (1979) examined some 13 indices as they might apply to the nuclear safety of two types of nuclear waste streams. These were packaged spent fuel from the once-through fuel cycle and solidified high level wastes from a coprocessed UO_2-PuO_2 fuel cycle. A hypothetical surface storage scenario was developed and seven of the

indices were calculated. The results evolved into two categories: index evaluation and fuel cycle waste comparisons. Five of the seven indices evaluated were found to be applicable to nuclear waste management. Those indices requiring detailed data input or those having related more to a specific site were not included in the evaluation.

Voss found that through the use of broad categories for hazards and the assumption of additive effects for constituents of the waste stream, a general comparison of relative hazards could be made between two types of radioactive wastes. This led to a general recommendation that removal of actinides, particularly plutonium, would substantially reduce the hazards. A similar series of indexing approaches might be appropriate for evaluating low-level radioactive wastes in shallow land burial facilities. However, the chemical characteristics of the low-level wastes could prove to be more significant in assessing hazards, and the indexing approaches proposed by Voss would necessarily be expanded to account for chemical interactions.

6.4 Chemical Hazard Assessment

Exposure and associated adverse efects are the two most important factors in evaluating hazards from chemicals. An essential consideration is definition of a dose-response relationship that can be used for extrapolation of effects to various dose levels. Often data are not readily available for most substances, and it becomes necessary to use substitute information to estimate exposures and effects (See Table 1). For example, the uptake or absorption of a compound, its persistence in the environment, and its mobility in various media are important in estimating probable exposures. Potential effects on man, the environment, and ecological systems are indicated primarily by laboratory toxicology studies, human clinical experience, epidemiologic studies, and field monitoring and observation. Acute effects in animals or humans are usually favored in assigning hazard rankings, but some chronic health impacts such as carcinogenicity and teratogenicity are also considered significant.

The predicted effects of a substance depend to a great extent on the dose-response relationship used in making projections. Because of a lack of data, the underlying

premises of the selected relationship can often be challenged, particularly when dealing with time-delayed and chronic effects. However, there have been a variety of pragmatic attempts to quantify the degree of risk or hazard for a given situation, and some of the approaches may be applicable to evaluating hazards of chemicals in shallow land burial sites.

6.4.1 Models and Dose Response

Fine (1971) has proposed a mathematical system for evaluating hazards by developing a risk score based upon consequences (C), exposure (E), and probability (P) of harm if exposed. Each of the relevant factors are assigned a cardinal value, and a risk score (R) is obtained by the product $R = C \times E \times P$. This exercise provides a technique for relative ranking of hazards. Fine also expands the technique to evaluate the justification (J) for taking corrective action by dividing the risk score (R) by a cost factor (CF) and an estimated degree of correction factor (DC). In this approach, a quantitative justification factor (J) is developed for the desirability (benefit/cost measure) of mitigating a hazard. Overall, this approach could provide a generalized quantitative means for evaluating hazards of chemicals and control strategies. The five factors in Fine's approach are as follows:

1. Consequences are the most probable result of the potential exposure or accident.

   a. Catastrophe (fatality, significant physical impairment)

   b. Less serious impairment

   c. Disability

   d. Lost time, not disability

   e. Minor injury or illness; minimal loss of time

2. Exposure is the frequency of occurrence of the hazard event.

   a. Many times each day

b. Frequently (1 per day)

c. 1 per week or month

d. 1 per month or year

e. Rare event, has occurred

f. Not known to occur

3. Probability is the likelihood that the injury, illness, or adverse physical effects will occur and that the sequence once initiated will go to completion.

   a. Most likely result

   b. Possible 50/50

   c. Unusual

   d. Remotely possible

   e. Conceivable

   f. Practically impossible

4. Cost factor ranking (for a proposed correction) is developed by direct dollar estimates or by a relative costs scale

   a. above $50,000

   b. 25,000 - 50,000

   c. 10,000 - 25,000

   d. 1,000 - 10,000

   e. 100 -1,000

   f. 25 - 100

   g. below 25

5. Degree of Correction Possible is a scaler from 0 to 1.0 indicating fraction of hazard being eliminated by proposed controls

In the more complicated and specific area of health effects where event and time determine the degree of exposure (risk estimation), several mathematical models have been explored to define dose-response relationships. Using such models, there is a need to develop information on the likelihood that adverse effects will occur as a result of potential levels of exposure. Mathematical models may also allow estimations of uncertainty in predicting risks, modeling risks from intended use, abuse, or misuse, and evaluating comparative risks.

From the discussion of Hoel et al. (1975) these mathematical models fall into one of two categories: dichotomous response models and time-to-occurrence models. The former group includes the most commonly used linear or one-hit model and the group of probit, logistic, and extreme-value models which are based upon cumulative distribution functions and their related characteristics. This series of models follows the general class of:

$$P_d = F(\alpha + \beta \log d)$$

where: P_d = probability of response at dose d
F = the distribution function
α and β = parameters of the distribution function that affect its characteristics

The second group, the time-to-occurrence models, relate time-to-occurrence of the response to dose, instead of simple incidence to dose. Several statistical distributions models, such as the lognormal and Weibull, have been applied to quantify the time effect of continuing dosages; however, use of these models with their more complex mathematics remains limited until further research is conducted to establish the maximum risk associated with exposure at low dose levels. The time-to-occurrence models for chronic health risk assessments, especially with carcinogenic substances, may be particularly desirable and useful.

Because of the current complexities and data unavailability in using more complex mathematical risk models, the most common mode is the linear or one-hit model. A practical example in the use of this model for risk assessment is described in the EPA report "Mathematical Evaluation of Kepone Levels", Thorsland and O'Mara (1977). The methodology followed by EPA in

this report permits the establishment of a defined action level based upon implied risks, or permits the assessment of risk for a given action level. The implicit assumption in defining action level is that the risk for any level below the action level is tolerable. Using experimental animal data and a functional form of the one-hit model, a simple linear equation relating probability of occurrence of tumors to total exposure was developed through a nonlinear weighted least squares curve fit. Next, the total exposed population was added to the equation, and the subsequent action levels in parts per million under different risk/benefit assumptions were calculated. Subsequently, the risk to the population was estimated based upon the proposed action levels. The underlying assumption in this kind of approach is that the probability of occurrence for "n" people over one year is the same as that for one person over "n" years.

While this type of analysis provides a quantitative means for assessing the population-at-risk and dose-response relationships, broad assumptions and averaged data are of necessity required to produce quantitative measures. The overall suitability of using such a quantitative approach depends on the data available for analysis.

6.4.2 Physical Chemical Properties and Toxicity Rankings

The most desirable approach for evaluating potentially hazardous chemicals would be to relate the toxicity, physical/chemical properties and reactivity of a specific compound to its transport and potential for harm to man, the environment, and ecosystems. The specific properties necessary for predicting transport and possible biological effects include: (a) water solubility, (b) heats of solution, (c) ionization constants, (d) vapor pressures, (e) rates of hydrolysis, and (f) partition coefficients. While these factors have been discussed in Chapters 3 and 5, they are also significant in assessing hazards and estimating of potential exposures. The influence of physical/chemical properties on environmental behavior and biological exposures is indicated in Table 6-2.

Table 6-2 RELATIONSHIP OF PHYSICAL/CHEMICAL PROPERTIES TO ENVIRONMENTAL BEHAVIOR*

Physical/Chemical Data	Related To
Solubility in water	Leaching, degree of adsorption, mobility in the environment
Latent heat of solution	Adsorption, leaching, vaporization from surfaces
Partition coeffient	Bioaccumulation potential, adsorption by organic matter
Hydrolysis	Persistence in environment and biota
Ionization Constant	Route and mechanism or adsorption or uptake, persistence, interaction with other molecular species
Vapor pressure	Atmospheric mobility rate of vaporization

*Adapted from Freed, et al (1977)

In many instances sufficient biological data are not available to completely define the toxicological impact of a given chemical. However, it is necessary to consider as fully as possible parameters such as the following:

1. Persistence and accumulation by biological systems.

2. Metabolic products. These may vary depending upon the physiochemical properties of the target organ into which the chemical is deposited.

3. Rates of absorption, metabolism and excretion of the parent compound and its metabolite(s). This may vary depending upon the concentration of the compound and the species exposed.

4. Synergism or antagonism of biological effects of various compounds and/or their metabolites in the target organism(s).

In evaluation of the relative hazards of chemicals, most ranking systems are based on characterizing effects. Sax (1975) one of the oldest and most cited approaches to toxicity evaluations, defines the various effects as follows:

- <u>acute local</u> - single exposures lasting seconds, minutes or hours

- <u>acute systemic</u> - absorption into the body by inhalation, ingestion, or through skin following single exposure lasting seconds, minutes, or hours or following ingestion of a single dose.

- <u>chronic local</u> - continuous or repeated exposures of the skin or mucous membranes extending over periods of days, months, or years.

- <u>chronic systemic</u> -absorption into the body by inhalation, ingestion or through the skin following continuous or repeated exposures extending over days, months or years.

The classifications of hazard (as defined by Sax) range from 0 to 3.

0 = no toxicity

(a) materials which cause no harm under any conditions of normal use.

(b) materials which produce toxic effects on humans only under the most unusual conditions or by overwhelming dosage.

1 = slight toxicity

(a) acute local - slight effects regardless of the extent of exposure.

(b) acute systemic - slight effects regardless of the quantity absorbed or the extent of exposure.

(c) chronic local - slight and usually reversible harm and the extent of exposure may be great or small.

(d) chronic systemic - only slight, usually reversible effects, and extent of exposure may be great or small.

In general, those substances classified as having "slight toxicity" produce changes in the human body which are readily reversible and which will disappear following termination of exposure, either with or without medical treatment.

2 = moderate toxicity

(a) acute local or moderate effects which may be the result of intense exposure for a matter of seconds or moderate exposure for a matter of hours.

(b) acute systemic - moderate effects.

(c) chronic local - moderate effects.

(d) chronic systemic - moderate effects.

Those substances classified as having "moderate toxicity" may produce irreversible as well as reversible effects in the human body. These changes are not of such severity as to threaten life or produce serious physical impairment.

3 = severe toxicity

(a) acute local - injury of sufficient severity to threaten life or to cause permanent physical impairment or disfigurement.

(b) acute systemic - injury of sufficient severity to threaten life.

(c) chronic local - injury of sufficient severity to threaten life or cause permanent impairment, disfigurement, or irreversible change.

(d) chronic systemic - death or serious physical impairment.

Another general approach is to characterize the degree of toxicity or hazard by mortality effects using LD_{50} values. Table 6-3 provides an example of such an approach which has been adapted from Thienes and Haley (1972) and Casarett and Doull (1975). There are six categories with warning phrases which indicates the degree of hazard associated with the degree of toxicity, as indicated by the LD_{50} values in animals. These phrases might be useful in advising and alerting workmen at a site as to required disposal techniques and protective measures. Based on LD_{50} values, one disposal criterion might be to limit the number of LD_{50} doses per unit volume or surface area of a site. LD_{50} values are particularly useful in ranking hazards but should not be used as the sole criterion. However, in evaluating chemicals, it may be desirable to use more than the 3 categories defined by Sax (1975).

Table 6-3 DEGREE OF HAZARD AND SUGGESTED RELATIONSHIP OF ANIMAL TO HUMAN SUSCEPTIBILITY*

LD_{50} In animals Dose/kg	Degree of Hazard	Probable Lethal dose for 70 kg man
1.0 mg	Dangerously Toxic	A taste
1-50 mg	Seriously Toxic	A teaspoonful
50-500 mg	Highly Toxic	An ounce
0.5-5 g	Moderately Toxic	A pint
5-15 g	Slightly Toxic	A quart
15 g	Extremely Low Toxicity	More than a quart

*Adapted from references Thienes and Haley (1972) and Casarett and Doull (1975) and 29

6.4.3 Criteria and Standards Approach

Another approach in controlling hazards is to specify or identify performance criteria which define acceptable standards. Cleland and Kingsbury (1977) recently developed such criteria in the form of multimedia environmental goals.

> Multimedia Environmental Goals (MEG's) are levels of significant contaminants or degradants (in ambient air, water, or land or in emissions or effluents conveyed to the ambient media) that are judged to be (1) appropriate for preventing certain negative effects in the surrounding populations or ecosystems, or (2) representative of the control limits achievable through technology.

The methodology developed for estimating goals for emission controls included the use of:

> ...(1) the concentrations described as ambient level goals based on hazards posed to public health and welfare as a result of long-term or continuous exposure to emissions; (2) natural background levels which provide goals for elimination of discharge; (3) and hazards to human health or to ecology induced by short-term exposure to emissions. Values for the last criterion were estimated as Minimum Acute Toxicity Effluents (MATE's) which are intended to serve both as relative hazard indicators and as estimated levels of effluent contaminants considered to be safe for short-term exposures Cleland and Kingsbury (1977).

The translation of various forms of data into Ambient Level Goals expressed as estimated

permissible concentrations (EPCs reported in common units) facilitates comparison of relative hazard potentials of potentially toxic substances regardless of media, thus providing the opportunity to establish meaningful management and control strategies for these substances.

The usefulness of the MATEs and EPCs, which are only approximations and may contain up to a factor of 10^3, is questionable. This can best be illustrated by the fact that the air/health MATE may vary by a factor of 100, depending upon whether the NIOSH standard or LD_{50} data is used to derive the MATE. For example, the air/health MATE for benzene is 3×10^3 $\mu g/m^3$ when derived from the NIOSH standard, and 1.7×10^5 $\mu g/m^3$ when derived from the LD_{50}. The respective methods of derivation are given below (Cleland, Kingsbury, 1977).

(1) MATE ($\mu g/m^3$) = 10^3 x TLV or NIOSH recommendation ($\mu g/m^3$)

(2) If carcinogenic, MATE ($\mu g/m^3$) = 10 x TLV or NIOSH recommendation ($\mu g/m^3$)

(3) If TLV not available, MATE ($\mu g/m^3$) = 45 x LD_{50} ($\mu g/kg$)

The utilization of different sets of assumptions and the discrepancies in the manner of derivation introduce a considerable degree of uncertainty in MATE calculations. Furthermore, there is a question of whether the water/health MATE is calculated from water data or from the air/health MATE; this may introduce another tenfold variation. It is then conceivable that the total uncertainty in the MATEs may be on the order of 10^3 or higher. Therefore, it is important to know the validity and appropriateness of the MATEs because any fallacies and/or discrepancies in the MATEs will be reflected and/or magnified when they are used in attempts to rank chemical toxicity.

Several comments concerning the MEGs-MATEs ranking system are necessary.

i. The use of threshold limit values (TLVs) for the purpose of calculating MATEs and EPCs is questionable. The 1977 TLVs,

published by the American Conference of Governmental Industrial Hygienists (ACGIH), specifically states that these limits are:

> ...intended for use in the practice of industrial hygiene and should be interpreted and applied only by a person trained in this discipline. They are not intended for use, or for modification for use as follows:
>
> (1) as a relative index of hazard or toxicity
>
> (2) in the evaluation of control of community air pollution nuisances
>
> (3) in estimating the toxic potentials of continuous, uninterrupted exposures, or other extended work periods...

In addition to the clear admonition regarding the use of TLVs, the handbook also states, "the amount and nature of the information available for establishing a TLV varies from substance to substance; consequently, the precision of the estimated TLV is also subject to variation and the latest documentation should be consulted in order to assess the extent of the data available for a given substance." Furthermore, formulae are provided in a series of appendices for use when two or more hazardous substances are present. The procedure recommended is that, in the absence of information to the contrary, effects of different hazards should be considered additive. The ACGIH states:

> "Antagonistic action or potentiation may occur with some combinations of atmospheric contaminants. Such cases, at present, must be determined individually. Potentiating or antagonistic agents are not necessarily harmful by themselves. Potentiating effects of exposure to such agents by

routes other than that of
inhalation are also possible."
(ACGIH, 1976)

2. The use of or LD_{50} values is subject to many of the same problems as is the use of TLVs. These values are based on mortality data only and do not take into account other biological activities such as cardiovascular, central nervous system, and muscular effects which may be important in evaluating the overall toxicity of a compound. In addition, these values are based on a single (acute) dose to an animal and it is difficult, if not impossible, to extrapolate these data to environmental situations.

3. Although the authors stated the derivation of the MATEs and EPCs was based on acute toxicity values, the authors have incorporated data for carcinogencity and for teratogenicity when available. These types of studies are not considered "acute." Two comments are in order:

   (a) The authors appear to equate teratogenesis with carcinogenesis. The reason for this is not clear. The former is a "one-time event" which can potentially affect a small proportion of the general population (pregnant women and unborn children). Carcinogenesis, by contrast, is a potential hazard for all of the population.

   (b) Incorporation of other potential risks, such as irreversible neurotoxicity, mutagenesis, and other subchronic or chronic effects including cardiovascular effects, have not been evaluated or incorporated into the derivation of MATEs and EPCs. It is reasonable to assume that these risks are important. (Frequently the acute manifestation of the toxicity of a compound in a given animal species is quite different from the subchronic and chronic effects in the same animal species.)

6.4.4 An Indexing Approach

Finally, an example of an indexing approach will be discussed. This involves a listing of relevant factors and developing an index to score each substance of interest. A series of steps designed to evaluate the quantity, quality, and value of the available information is presented as follows:

A. Is all necessary toxicity information relevant to a hazard assessment available and sufficient?

   1. Carcinogenic
   2. Mutagenic
   3. Growth Alteration
   4. Behavioral Disorders
   5. Cumulative Effect
   6. Combinative Effect
   7. Any Other Effect

   If it is not available, assign a scaler factor to indicate quantity and relevance of derived data.

B. Does the substance show any of the following?

   1. Persistence (air, water, land, biota)
   2. Acute Toxicity (dose)
   3. Chronic Toxicity (dose)
   4. Any other significant characteristic

   If so, rate on comparative scale with persistence highest and "other" lowest.

C. Is the substance present available in substantial amounts (i.e., anticipated number of LD_{50} doses produced)?

D. Is the substance a mixture of chemicals having an unknown or unpredictable effect? If so, list the percentage composition for the most prevalent component and multiply by the number of significant ingredients.

E. What is the degree of hazard reduction that can be achieved?

F. What is the estimated relative cost of the various management options for various degrees of hazard reduction?

G. Rank all chemical substances by calculating a hazard ranking (HR) as follows:

$$HR = \frac{A \times B \times C \times D \times E}{F}$$

6.5 Relative Hazard Rankings

There are a variety of approaches that might be applicable to relative hazard rankings. Four possible approaches with advantages and disadvantages are discussed in this section and are also summarized in Table 6-4. Committee 17 of the Environmental Mutagen Society (1975) has proposed an approach which might be useful in comparing relative hazards of exposure to ionizing radiation and exposure to a chemical. The basic concept is to define a rem-equivalent-chemical (REC) as that dose or product of concentration multiplied by time which produces an equivalent amount of genetic damage equal to that produced by 1 rem of chronic radiation exposure. Relative data were provided for three substances: hycanthone methanesulfonate, ethyl methanesulfonate, and sodium nitrite. After correction for radiation dose rates and sensitivity of the tests sytems the REC values were calculated as ranging from 1 to 1.8 mg/Kg, 0.62 to 0.83 mg/Kg, and 7.8 mg/Kg respectively. These REC values were based on various mutagenicity assays and reflect the relative amounts for each of the chemicals required

TABLE 6-4

POSSIBLE APPROACHES TO RELATIVE HAZARD RATINGS
FOR TOXIC CHEMICALS AND LOW-LEVEL RADIOACTIVE WASTES

ALTERNATIVE	SUITABILITY	LIMITATIONS
REM-EQUIVALENT-CHEMICAL	Carcinogenic, Mutagenic, Teratogenic Substances	Significance of dose-response and safety standards undefined, depends on level of acceptable risk
MPC/EPC-AIR and Water Equivalents	Performance criteria, Disposal Volumes, Off-Site Concentration Limits	Depends on validity of MPC/EPC, limits subject to change
Equivalent Hazard Categories	General Toxic Effects, Based on Definitive Data	Data base is usually acute rather than chronic toxicity
Site-Specific Risk Management Committee	Responsive to local conditions, credible understandable to local population	Potentially subjective, changes in value. Judgements with time or committee members.

to yield effects similar to X-rays. However, there appears to be no definitive relationship between the REC value based on mutagenicity and LD_{50} values tabulated by NIOSH (1977). Thus the REC approach might be applicable to evaluating relative effects of chemicals that are mutagenic, teratogenic or carcinogenic, but would not necessarily be applicable to predicting other equivalent effects.

Another approach to developing a relative hazard ranking for chemicals and low-level wastes would be to make use of MPCs in air and water for radioactive materials and the EPCs for air and water for chemicals. Essentially, the hazards could be ranked by the volumes of air or water necessary to meet the MPC or EPC concentration limits. In this manner, a radiation hazard and a chemical hazard requiring equivalent amounts of air or water to satisfy either an MPC or EPC would be regarded as having the same relative hazard. This approach could also be useful in specifying performance criteria and disposal limits for particular sites.

Another possible approach would be to define from three to six hazard categories for radioactive substances similar to the ranking of chemicals by LD_{50} values as indicated in Table 6-3. Using independent criteria for assigning radioactive substances to a hazard category defined as comparable to a similar chemical hazard category, it would be possible to develop methods for equivalent hazard rankings for low-level wastes and chemicals.

Any of these and other approaches could be facilitated by use of expert committees. Essentially, the evaluation of hazards for either radioactive wastes or chemicals would be performed separately. Subsequently, using a defined methodology involving conversion formulas, appropriate concentration limits, or equivalent hazard categories the control and management guidelines for a specific site could be developed. Such an approach and use of an expert committee might be incorporated into a risk assessment and hazard control plan at each specific site. In this manner, risk management strategies could be designed to match the characteristics of each site.

6.6 Summary

A variety of methods have been proposed in the literature to assess radiotoxicity or relative hazards for radionuclides. Virtually all of the methods make use of the MPC values as a starting point. Refinements include consideration of such factors as the probability of taking a certain quantity of the nuclide into the body, the transport of nuclides through the environment (including foodstuffs), and the probability of removing concentrations of nuclides from some location (such as a burial site). It is clear that the reliability of any such index of relative hazard will depend on the limitations associated with the MPC values and on a knowledge of the movement and transport of nuclides (or chemical compounds containing nuclides) from the environment to man.

As an initial approach to evaluating the overall toxicity or the relative hazard of the low-level radioactive wastes, the use of the MPC as currently specified is probably adequate as a measure of radiotoxicity. This should be appropriately coupled with a suitable chemical toxicity index to provide an overall radio-chemical toxicity rating. Refinements dealing with the movement of various radioactive chemical forms from the waste site to the environment and to man could be added in assigning an overall hazard index for a particular compound.

Chemical hazard assessment is based on evaluation of exposure and adverse effects data. Such data may be incomplete and show varying degrees of uncertainty. Also there is generally a lack of definition for dose-response relationships at low-levels of potential exposure, and hazard assessments are often based on averaged data and broadly based assumptions concerning the dose response. A variety of approaches may be applicable to assessing hazards of chemicals in shallow land burial sites. The hazard assessment methodology applied needs to be based on defined procedures. While ranking of chemical hazards at a site depends to some extent on site-specific characteristics, it would be possible to rank hazards on the basis of exposures assumed for a typical site and potential adverse effects of a particular substance. A variety of approaches may be applicable to assessing hazards of chemicals in shallow land burial sites. The hazard assessment methodology applied needs to be based on

defined procedures. While ranking of chemical hazards at a site depends to some extent on site-specific characteristics, it would be possible to rank hazards on the basis of exposures assumed for a typical site and potential adverse effects of a particular substance.

7.0 RECOMMENDATIONS

7.1 Issues Regarding Shallow Land Burial Sites

The licensing and regulation of shallow land burial facilities involves a number of issues related to the chemical characteristics of the wastes and the assessment of chemical toxicity and radiological toxicity. These issues include:

- The effects of chemicals in the waste on the design parameters of the facility.

- The identification and elimination of chemicals in the waste that will enhance migration of toxic materials or degrade performance of the facility.

- The concentrations of such chemicals necessary to damage facility performance.

- Identification of exposure concentrations and conditions potentially hazardous to reclaimers.

- The influence of solidification agents (ureaformaldehyde, DOW polymer, asphalt, or cement) on performance of the facilities.

- The health and safety of personnel potentially exposed to toxic chemicals.

- The influence of on-site treatment systems such as incineration, concentration, or solidification of wastes on enhancement or mitigation of chemical hazards.

- Possible disposal of low-level radioactive wastes at alternative sites for chemicals found to exceed the radioactive hazard.

- Advantages and disadvantages of segregating fuel cycle wastes from non-fuel cycle wastes.

- Chemical monitoring of sites.

Many of the chemical, regulatory, and environmental aspects of these issues are similar. Sections 7.2 through 7.3.1.5 provide a detailed discussion of these issues.

7.2 Chemical Aspects

7.2.1 Design Parameters

The potential effects of chemicals in the waste on the design parameters of a facility appear to be minimal based on current waste volumes and the proportion and distribution of chemicals in the wastes. The magnitude of any potential effects depends on the ratio of radioisotopes to total material as well as the extent of contact between the chemical and radioactive materials in the waste. Potential effects may be enhanced by the amount of water percolating through the buried wastes. Based on the geohydrological factors discussed in Chapter 5, it appears unlikely that the existing quantities of chemicals in the wastes would enhance the transport of radioactive material off-site unless there were a substantial loss of control over the trench waters. Provisions for continued control and monitoring of trench waters are essential during the period of active site life and post closure of a site. Thus, to the extent that water percolates through, and contacts the chemical wastes, any water soluble material containing radionuclides would be subject to transport. The natural barriers which would prevent transport off-site are the integrity of containers, the use of water resistant barriers such as plastic covers, soil cover, and paving materials , and the collection and treatment of contaminated water. These must be evaluated on a site-specific basis, and integrated into the design and operation of the site as appropriate.

7.2.2 Prevention of Chemical Interactions

Formation of soluble complexes of radionuclides by interactions such as ion exchange, displacement reactions, changes in surface energies by surfactants, and chelation could result in enhanced transport of radionuclides and toxic materials. Insoluble complexes can also be formed by similar interactions and may impede chemical transport. However, given current waste characteristics, volumes, and burial ground practices, there appears to be no significant potential for the transport of radionuclides and toxic chemicals off-site. The likelihood of any such phenomena

could be further decreased by modifying current burial practices. Such modifications could include segregation of non-fuel cycle wastes, disposal at arid sites, maintenance of packaging integrity, and improved management of water flows, accomplished by capping of the trench, treatment of leachates, and monitoring of aquifers. These recommended modifications are based primarily on the generally low concentrations of materials and small total quantities involved compared to the total fill volumes. For example, chelating agents such as EDTA are present in low amounts, and since the potential concentrations are low, soluble metal complexes are less likely. However, there may be special conditions or wastes that require special handling and disposal procedures. For example, the disposal of large quantities of chelating agents from large scale decontamination operations could require special disposal procedures.

7.2.3 Minimization of Migration Effects

It is recommended that chemicals, such as chelating agents, surfactants and strong acids or bases be regulated to avoid development of significant concentrations in trench waters and to prevent mobilization of radionuclides and toxic chemicals. Based on the inventory of wastes in Chapter 2, such materials would most likely come from UF solidified wastes, which produce an acid (pH 1.5-2) liquid in a polymerization reaction. Safety personnel at several institutions who were interviewed for this study did not provide sufficient details concerning the types or quantities of materials being submitted as low-level radioactive waste to allow specific chemical characterizations. Therefore, considerable uncertainty exists regarding the specific nature of these materials.

The list of radioactive research chemicals produced reveals that numerous materials, both organic and inorganic are being used (see Table 3-3 and Appendix B). The costs of such research chemicals are relatively high and it is unlikely that substantial quantities of these materials would find their way into the wastes. Thus the radioactive research chemicals would be present at

relatively low concentrations when compared to other materials such as cellulose, plastic, animal carcasses, tissues, and similar bulk wastes. There may be other materials being submitted for disposal which are unrelated to wastes from radioactive chemicals used in research projects, but the current status of data does not allow an evaluation of the impact of such materials. It is recommended that non-radioactive wastes be excluded from the disposal sites through the use of licenses and permits.

7.2.4 Prevention of Potentially Hazardous Conditions for Personnel

Potentially hazardous conditions at burial sites could be reduced by better waste characterization. Through more stringent enforcement of current regulations, it is recommended that licensees identify, as completely as possible, the nature, toxicity, and approximate quantities of these low-level waste materials. Such improved waste characterization would alleviate many of the potential problems associated with determining the protective devices which are necessary and sufficient at a particular disposal site.

Institutional low-level wastes appear to be composed predominantly of organic materials. Incineration of combustible wastes, followed by a solidification treatment (e.g., cement, or ion exchange resins) to immobilize any metallic ions present, may be the most appropriate solution to the problem. Considerable attention should be given to a potential increase in hazards to institutional workers resulting from the extra handling of the waste. This also includes evaluating the operational safety of processing radioactive and toxic materials.

The waste form and container, the construction of the trenches, the nature of the overburden and trench capping, and the control and treatment of any water are design factors used to avoid or to prevent contact of the wastes with water. If

this contact can be minimized, then the quantities of chemical waste disposed in the site should have no discernable effect on the performance of the facility. If the potential exposure concentrations are related to the quantity of the offending material per unit volume of disposal package, and if the material is volatile, or is degraded by natural processes to a volatile constituent with toxic properties, then such material could escape by diffusion through the overburden and trench cap to pose a potential exposure problem. Improper packaging of very toxic or volatile materials could create exposure problems for site workers. There is a need to improve the enforcement of license provisions for waste generators to insure the proper and adequate packaging of materials submitted for disposal.

7.2.5 Measures to Mitigate Exposures

The control of exposures is primarily accomplished by measures to prevent release of materials. Once materials are released, prevention of exposures and adverse effects is accomplished by measures to contain and remove the wastes by treatments such as chemical neutralization, solidification, concentration, repackaging, burial, and isolation. Segregation of the non-fuel cycle wastes from fuel cycle wastes, better packaging of toxic materials, and measures to improve control over personnel exposure and material handling procedures would also serve to lessen the consequences of a release. All of these recommendations would provide improvements in the control over any environmental or occupational exposures and any potentially hazardous waste materials.

Individuals may at some time in the future engage in excavation activities, legitimate or otherwise, to recover buried material. Any associated hazards of such activities would depend primarily on the characteristics of the chemical hazard presented by the material, and the mode of action on the individual being exposed. For example, direct

contact, ingestion, or inhalation may be required for a toxic effect. For those chemicals degraded in the burial trench, the time factor is pertinent to a consideration of potential effects, a 100 year post closure period is generally assumed. The type of matrix in which the material in question is contained would also be pertinent to determining any exposure concentrations produced by excavation activities. A concentration requiring the inhalation or ingestion of gram quantities of trench material in order to have a toxic effect could be considered of low significance. Volatile toxic chemicals of long persistence would be hazardous if they were still present in unbreached packages at the time of reclamation. However, it seems unlikely that the package would retain its integrity in the burial ground long enough to be a problem to a reclaimer. Some toxic materials are disposed in relatively high concentrations (within any given container at low-level waste burial facilities). For example, magnesium fluoride is buried in drum quantities. This material is given a toxicity rating of 3 by Sax, and could be expected to present an inhalation and ingestion hazard to reclaimers working in an area where this material had been buried. Precautions could be taken to minimize or eliminate this hazard, and to warn personnel, provided the presence of the material was anticipated and appropriate planning accomplished before entry to such a zone.

7.2.6 Influence of Solidification Agents on Hazards

Ion exchange resins used for cleanup of radioactively contaminated water from various plant operations, and urea-formaldehyde and related polymers used for solidification of concentrated aqueous wastes, may also be present in the low-level waste. The existence of a potential hazard to the reclaimer from these agents would be determined by the extent to which these materials underwent chemical degradation in the burial ground before attempts at reclamation. For example, the polyvinylstyrene-based resins may undergo a degradation to yield benzene, styrene, and related aromatic residues. These could present a hazard to the reclaimer if handled carelessly or without adequate precautions. Because

of the potential release of aromatic solvents at low-level waste sites, the hazard to reclaimers is larger than those of other operations. More information is needed on the long term reactions of these materials in the soil environment to provide a precise assessment of the probability of their being problems at a later date. Asphalt-immobilized waste materials could, theoretically, present a fire hazard resulting in liberation of aerosols bearing metallic salts. The French have had many years experience in the use of asphalt as a solidification agent for radioactively contaminated residues, and have reported that the asphalt in such an application will not sustain combustion unless the temperature is high enough (flash point of 550-600°F). In the absence of sodium sulfate, the use of asphalt for immobilizing waste provides a highly insoluble and stable matrix without posing a significant fire hazard. The principal hazard foreseeable as a result of encountering cement-solidified wastes during a reclaiming operation would result from suspension of fine cement-dust which could, on extended exposure, lead to silicosis or related lung diseases. This hazard could be avoided through dust control or by requiring the use of respiratory protective devices at high dust concentrations. Because of the frequent use of cement solidification high dust concentrations and more likely than with the other operations.

7.2.7 Prevention of Hazards Associated with Handling Materials

To the extent that chemically toxic materials may escape into the surrounding burial site environment, a hazard to operating personnel exists. Of the institutions and organizations contacted during the surveys made in connection with this project, however, all were packaging such material in steel drums. In addition, those who were shipping scintillation liquids surrounded by an absorption medium were using steel containment waste packages surrounded by absorbent and enclosed in a second steel package. Thus, the likelihood of exposure to these materials at the burial site is low provided ordinary care is used in the handling of the packages. The packaging of these scintillation liquids in steel drums is not a regulatory requirement, but may be a license condition at the disposal site; therefore, guidelines should

indicate that it is a preferred method of disposal. Breached containers of bulk waste material, such as magnesium fluoride, could present a problem to waste site operators. All the operating disposal sites have procedures for handling breached packages. Proper precautions should minimize any difficulties resulting from breached packages.

In addition to a reduction in waste volume, incineration of non-fuel cycle wastes could eliminate the potential problems associated with toxic organic materials. When the residues are appropriately immobilized (for example, in asphalt) the hazards from any non-volatile toxic materials such as metallic salts should be eliminated. However, incineration may present certain problems (such as airborne transport, occupational exposures, political difficulties, cost, technology, and state of the art) at the waste generator's site, which should be evaluated and factored into any consideration of the advisability of using incineration. Other volume reduction systems, such as evaporation of liquid wastes, have an undefined effect and need to be evaluated on a case by case basis. If, for example, a waste liquid contained both volatile and non-volatile toxic materials, evaporation would lead to the creation of two waste streams where only one existed previously.

7.2.8 Regulation of Disposal Practices

Enforcement of regulations related to packaging and transportation of radioactive materials should provide adequate protection for transportation workers and burial ground operators from any chemical hazard present in wastes and likely to be shipped to the low-level waste site. However, in the absence of a quantitative definition of the radioactive vs. the chemical hazard of waste received at disposal sites, regulatory emphasis must be placed on reducing toxic chemical content in the packaged waste at the waste generator's site.

Regulations are needed for institutional generators of radioactive waste. These regulations should preclude the addition of non-radioactive but toxic waste materials to the waste going to the low-level waste disposal sites. As a general guideline for acceptable public exposure, facilities should operate within the guidelines set forth in 10CFR20.304 (attached as Appendix J). Chemically toxic materials contaminated with radioisotopes having a half life of one hundred days or less might also be diverted to hazardous chemical waste sites. Strict packaging requirements are essential for any such toxic materials contaminated with radioactivity which are sent to hazardous chemical waste facilities. These packaging requirements are essential as supplemental guidelines on the institutional licenses. Any additional regulations should be sufficient to protect the health of the public.

The following points summarize the regulatory implications:

a. Packaging regulations are promulgated by DOT, for licensees generating toxic materials contaminated with radioactivity.

b. Regulations relating to identification of materials going to low-level disposal sites should be amended to require more precise descriptions of the materials present in any wastes submitted for disposal.

c. Existing regulations limiting the chemical toxicity of material in low-level waste should be enforced, and amended if necessary to require a certification from the waste generator concerning the chemical toxicity of the materials.

d. Regulations should be promulgated identifying in specific terms the chemically toxic materials which may be sent to hazardous chemical waste sites. Any substances not specifically identified need to be evaluated and determined to have a lesser degree of hazard than specific toxic materials on a permit or license before disposal at a site is allowed.

7.2.9 Environmental Aspects

Adequate records are essential to allow for specific identification of hazardous materials, to know the amount and location of such materials, to identify potentially exposed workers, to know what actions are necessary for emergencies, and to maintain a history of site operations. Surveillance and monitoring are necessary to ensure that no adverse effects are occurring, that substances buried at a site are within acceptable limits, and that any trends in a degradation of the site or the surrounding environment can be detected. Standards and performance criteria are essential to ensure that operation of the site provides a safe working environment, and protects environmental quality and public welfare. A formal program for control of hazards is essential and requires periodic inspections, designation of special hazard areas, use of appropriate protective devices, and application of engineering controls. Finally, effective risk management requires development of contingency plans to deal with unusual events and emergency situations. These recommendations and requirements for management of shallow land burial facilities will be discussed in the following sections.

7.3 Maintenance of Adequate Records

Records are needed to provide data for assessment of hazards from potential exposure to low-level radioactive wastes and toxic chemicals, to evaluate the effectiveness of control measures, and to detect trends which could provide an indication of potential problems. The records should identify the chemical nature of the wastes, amounts, location, and potential exposures of personnel or the environment. The recordkeeping should be an integral part of the quality control plan to ensure that only approved materials are being deposited at the site. Also, results of measurements, test-borings, environmental samples, unusual circumstances, and personnel monitoring should be recorded to define potential exposures and changes in site operations.

7.3.1 Identification of Materials

Materials must be identified by use of standardized nomenclature. This approach allows ready access to computer-assisted information storage and retrieval systems. Chemical nonmenclature for use in computer systems should conform to an online chemical dictionary such as the National Library of Medicine's CHEMLINE. Other sources that could be consulted for standardized nomenclature are the Chemical Abstracts Service registry, NIOSH's registry of Toxic Substances, EPA's inventory of toxic substances in commerce, and standard references in chemistry and toxicology such as those listed in Volume II. Also in identifying materials for disposal, labels indicating the degree of hazard of toxicity need to include standardized warnings similar to those listed in Table 6-3. Adequate and proper identification of materials is essential to the recognition of potential hazards and application of suitable controls.

7.3.1.1 Inventory of Hazardous Wastes

A complete inventory of hazardous wastes is essential to evaluation and management of risks from potential exposures. The

inventory for a site needs to provide a quantitative measure of the wastes and a ranking of hazards. Classifying the wastes into categories similar to those indicated in Tables 3-2 and 3-3 would be useful as an initial approach. A further division that might be useful would be to rank materials within a given category by the degree of toxicity based on the LD_{50} values as indicated in Table 6-3. There is a need to describe the inventory of materials in commensurate terms. For example, approaches to the listing could be the weight of material per cubic meter, the number of toxic doses in a cubic meter for an average human, or the volume of materials per cubic meter of fill.

7.3.1.2 Materials Spills, Unusual Events, and System Failures

Records of accidents and failures in the performance of the burial site are necessary to highlight potential exposure problems in the employee group or with environmental quality. Material spills, unusual events, system failures, and accidents need to be investigated. The personnel potentially exposed, any monitoring data, and any medical findings need to be recorded. The agent, part of body or system effected, circumstances, degree of disability, personal protective devices in use, and engineering or administrations controls in use should be included in reports.

7.3.1.3 Meteorological Conditions

A record of the rainfall at a site is required to evaluate the flow of water and to provide data for design and operation of the water management system. The penetration of water into a site should be evaluated by soil moisture determinations. The site needs to be inspected periodically to ensure the integrity of capping material and to correct any potential deficiencies produced by burrowing animals, erosion, or other factors.

7.3.1.4 Monitoring Data

Data on environmental quality, employee exposures, and performance of the site are required to provide periodic evaluation of risks associated with site operations. There are two main areas of data collection comprising on-site monitoring and off-site monitoring. On-site monitoring includes employee exposure monitoring, water sampling, air quality measurement, analysis of wastes for quality control, and tests to monitor site performance. Off-site monitoring includes air and water quality determinations, monitoring of potentially affected areas and communities for residues, detection systems for trends indicating potential changes or emerging problems in the surrounding areas. There are very few monitoring and analytical methodologies recommended in the literature, however, those available are in the bibliography contained in Volume III.

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APPENDIX A

LETTER SENT TO PROSPECTIVE INTERVIEWEES, NON-FUEL CYCLE WASTE SURVEY

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LETTER SENT TO PROSPECTIVE INTERVIEWEES, NON-FUEL CYCLE WASTE SURVEY

E. R. JOHNSON ASSOCIATES, INC.

8206 LEESBURG PIKE

VIENNA, VIRGINIA 22180

TELEPHONE 703-893-7378

E. R. Johnson Associates, Inc. is providing technical support to General Research Corporation for a project supported by the U.S. Nuclear Regulatory Commission.

It is the intent of this study to identify the chemical forms of materials present in and associated with low-level radioactive wastes being delivered to shallow land burial sites.

We are requesting your help and assistance in the project. Any information received from your organization will be identified only as to the generic source; i.e., institutional, research laboratory, or industrial waste. We recognize that these low-level waste may contain a wide variety of chemicals; the information obtained through this study will aid in identification of the significance of these wastes from the standpoint of their potential chemical toxicity, and in evaluation of current disposal techniques. Information which you supply concerning the chemical species in your operational type of waste will not be used as an evaluation of your industry, but to aid the NRC in developing regulations, standards and criteria for low-level waste management, including operation, monitoring and long-term care of disposal sites.

The type of information we are hoping you can provide includes the following:

Chemical nature of radioactive wastes (e.g., nitrate salts, sulfate salts, inorganic ion exchange resins, organic resins [specify trade name or chemical identity], organic compounds, organic solvents, etc. We are interested in the most specific identification available).

Type of storage sent (boxes, drums, etc.)

Volume of soidified liquids and method of solidification and/or absorption.

Volume of solid waste.

If you have your material packaged by a commercial firm, we would be interested in the chemical composition of materials sent to the packager.

A follow-up telephone call by one of our technical staff, Mrs. Miriam Pellettieri, will be made a few days after you receive this letter. We hope you will be able to assist us.

Sincerely,

J. A. McBride
Vice President

APPENDIX B

CATEGORIES OF LABELED COMPOUNDS MANUFACTURED FOR RADIOCHEMICAL USE

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CATEGORIES OF LABELED COMPOUNDS MANUFACTURED FOR RADIOCHEMICAL USE

Amino Acids, Peptides and Proteins:

146 compounds were listed of which the following 13 are a representative sample:

S-Adenosyl-L[*carboxyl*-^{14}C]methionine

L-[U-^{14}C]Alanine

^{14}C and ^{3}H Amino acid collections and mixtures

p-Amino[^{3}H]hippuric acid

L-[*guanido*-^{14}C]Arginine monohydrochloride

DL-[*methyl*-^{14}C]Carnitine hydrochloride

L-[*carbamoyl*-^{14}C]Citrulline

L-3,4-Dihydroxy[*ring*-2,5,6-^{3}H]phenylalanine

N-Formyl-L-[^{35}S]methionine sulphone

L-[^{35}S]Homocysteine thiolactone hydrochloride

L-[U-^{14}C]Homoserine

DL-5-Hydroxy[*methylene*-^{14}C]tryptophan

DL-[*benzene ring*-U-^{14}C]Tryptophan

Agricultural Chemicals:

35 compounds were listed of which the following 7 are a representative sample:

[^{14}C]Aldrin

[^{14}C]Arprocarb

γ-[U-^{14}C]Benzene hexachloride

[^{14}C]DDT

Agricultural Chemicals (continued):

Dimethyldi[^{35}S]thiocarbamic acid, potassium salt

[^{32}P]Malathion

[^{14}C]Warfarin

Drugs, Carcinogens, Hormones, Vitamins, and Other Compounds of Medical Interest:

156 compounds were listed of which the following 19 are a representative sample:

[1-^{14}C]Acetyl salicylic acid

[^{3}H]Actinomycin D

DL[7-^{14}C]Adrenaline DL-bitartrate

d-[*methylene*-^{14}C]Amphetamine sulphate

[G-^{3}H]Atropine

[G-^{3}H]Benz[*a*]anthracene

D-*threo*-[*dichloroacetyl*-1-^{14}C]Chloramphenicol

Concanavalin A, *N*-[*acetyl*-^{3}H]acetylated

Cyano[^{57}Co]cobalamin

[7-^{14}C]Dibenz[*a*,*h*]anthracene

N,*N*-Di[^{14}C]methylnitrosamine

[^{3}H]Dopamine hydrochloride

[1(n)-^{3}H]Heroin

[*ring*-2-^{14}C]Histamine dihydrochloride

[G-^{3}H]soniazid

[^{35}S]Mustard gas

[*carbonyl*-^{14}C]Nicotinamide

[1,4-^{14}C]Putrescine dihydrochloride

[^{35}S]Sulfamethazole

Carbohydrates:

75 compounds were listed of which the following 6 are a representative sample:

N-Acetyl-D-[1-^{14}C]galactosamine

L-[1-^{14}C]Arabinose

Carbohydrates (continued):

2-Deoxy-D-[1-^{3}H]glucose

L-[1-^{14}C]Fucose

L-[1-^{3}H]Fucose

and other ^{3}H and ^{14}C substituted carbohydrates

Nucleotides:

97 compounds were listed of which the following 11 are a representative sample:

[*adenine*-U-^{14}C]Adenosine 3',5'-cyclic phosphate

[2,8-^{3}H]Adenosine 3',5'-cyclic phosphate

Adenosine 3',5'-cyclic [^{32}P]phosphate

[U-^{14}C]Adenosine 5'-diphosphate

[2-^{3}H]Adenosine 5'-diphosphate

Cytidine 5'-diphospho[*methyl*-^{14}C]choline

Cytidine 5'-[α-^{32}P]triphosphate

Deoxy[U-^{14}C]guanosine 5'-triphosphate

Deoxy[8-^{3}H]guanosine 5'-triphosphate

Deoxy[5-^{3}H]uridine 5'-triphosphate

5-[^{125}I]Iodo-2'-deoxycytidine 5'-triphosphate

Nucleotide Sugars:

13 compounds were listed of which the following 3 are a representative sample:

Adenosine diphospho-D-[U-^{14}C]glucose

Guanosine diphospho-L-[U-^{14}C]fucose

Uridine diphospho-*N*-acetyl-D-[U-^{14}C]glucosamine

Protein Labelling Reagents:

20 compounds were listed all of which are listed below:

[^{3}H]Acetic anhydride

Bolton and Hunter reagent

[*N*-*methyl*-^{14}C]Dansyl chloride

Protein Labelling Reagents (continued):

[G-^{3}H]Dansyl chloride

[^{3}H]DFP

[^{32}P]DFP

N-Ethyl[2,3-^{14}C]maleimide

1-Fluoro-2,4-dinitro[U-^{14}C]benzene

1-Fluoro-2,4-dinitro[3,5-^{3}H]benzene

N-Formyl-L-[^{35}S]methionine sulphone
(intermediate for *N*-formyl-methionyl sulphone methyl phosphate)

Iodine-125, codes IMS.30/300

Iodine-131, codes IBS.3/30/500

Iodo[1-^{14}C]acetamide

Iodo[2-^{14}C]acetic acid

Iodo[2-^{3}H]acetic acid

Phenyl[^{14}C]isothiocyanate

Phenyl[^{35}S]isothiocyanate

Sodium boro[^{3}H]hydride

[1,4-^{14}C]Succinic anhydride

N-Succinimidyl[2,3-^{3}H]propionate

Fatty Acids, Prostaglandins and Related Lipid Products:

80 compounds were listed of which the following 14 are a representative sample:

[1-^{14}C]Acetic acid, sodium salt

[^{3}H]Acetic acid, sodium salt

[1-^{14}C]Acetylcholine chloride

[^{3}H]Acetylcholine chloride

[5,6,8,9,11,12,14,15(n)-^{3}H]Arachidonic acid

Cholesteryl[1-^{14}C]oleate

Glycerol tri[1-^{14}C]oleate

[1-^{14}C]Linoleic acid

[1-^{14}C]Linolenic acid

[1-^{14}C]Oleic acid

[1-^{14}C]Palmitic acid

Fatty Acids, Prostaglandins and Related Lipid Products (continued):

Phosphatidyl[*N-methyl*-^{14}C]choline

[1-^{14}C]Prostaglandin E_2

[*N-methyl*-^{14}C]Sphingomyelin(bovine)

Purines and Pyrimidines:

31 compounds were listed of which the following 11 are a representative sample:

[8-^{14}C]Adenine

[2-^{3}H]Adenine

Benzyl[8-^{14}C]adenine

5-Bromo[6-^{3}H]uracil

[8-^{14}C]Guanine sulphate

[8-^{3}H]Guanine sulphate

[5-^{3}H]Orotic acid

[6-^{14}C]Orotic acid

[2-^{14}C]Thymine

[6-^{3}H]Thymine

[5-^{3}H]Uracil

Nucleosides:

42 compounds were listed of which the following 11 are a representative sample:

[8-^{14}C]Adenosine

[2-^{3}H]Adenosine

S-Adenosyl-L-[*methyl*-^{14}C]methionine

5-Bromo-2'-deoxy[1'2'-^{3}H]uridine

[5-^{3}H]Cytidine

[8-^{3}H]Guanosine

[8-^{14}C]Inosine

[2-^{14}C]Thymidine

[*methyl*-^{3}H]Thymidine

[2-^{14}C]Uridine

[5-^{3}H]Uridine

Steroids:

86 compounds were listed of which the following 14 are a representative sample:

[4-^{14}C]Aldosterone

[1,2,4(n)-^{3}H]Betamethasone

[11,12(n)-^{3}H]Chenodeoxycholic acid

[4-^{14}C]Corticosterone

Dehydro[7(n)-^{3}H]epiandrosterone

[G-^{3}H]Digitoxin

[4-^{14}C]Estradiol

[4-^{14}C]Estrone

[1-^{14}C]Glycocholic acid, sodium salt

18-Hydroxy[1,2(n)-^{3}H]corticosterone

[*carboxyl*-^{14}C]Lithocholic acid

19-[4-^{14}C]Nortestosterone

[7(n)-^{3}H]Progesterone

[1,2,6,7(n)-^{3}H]Testosterone

Radionuclides:

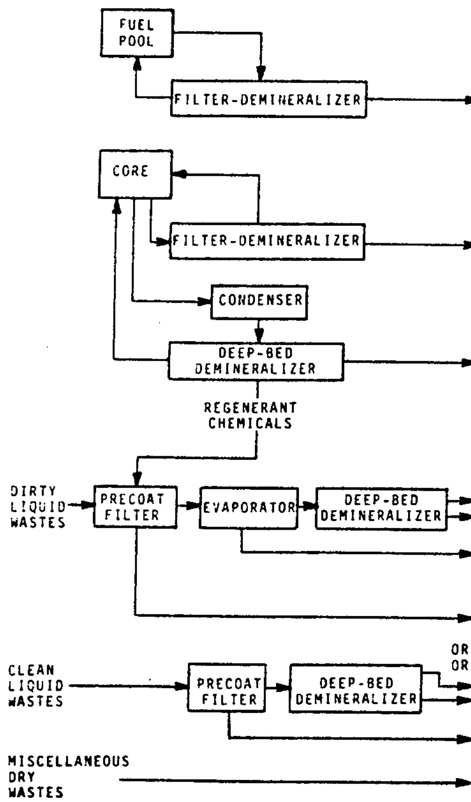
Ninety-one isotopes of 64 elements representing nearly the entire spectrum of the periodic table.

APPENDIX C

SOURCES AND CHARACTERISTICS OF NON-GASEOUS WASTES FROM 1-GWe BWR WITH DEEP-BED CONDENSATE CLEANUP

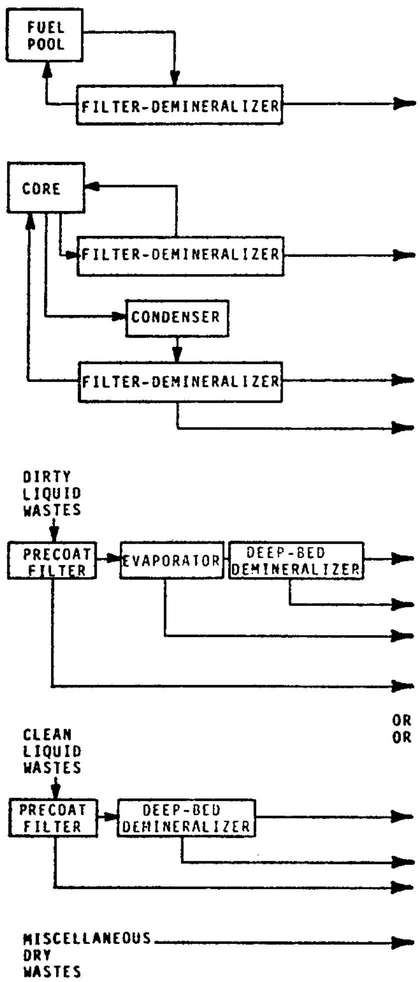
APPENDIX C

SOURCES AND CHARACTERISTICS OF NON-GASEOUS WASTES FROM 1-GWe BWR WITH DEEP-BED CONDENSATE CLEANUP



PRIMARY WASTE PER GWe-year			
FORM	UNCOMPACTED VOLUME m^3	RADIO-ACTIVITY Ci	TYPE
POWDERED RESINS	2.0 E0	<1.0 E1	COMBUST. β-γ
BEAD RESINS	4.8 E0	1.0 E3	COMBUST. β-γ
BEAD RESINS	9.9 E0	5.0 E0	COMBUST. β-γ
PURIFIED LIQUID BEAD RESINS	2.8 E0	5.0 E0	COMBUST. β-γ
SLURRY ∿25% DISSOLVED SOLIDS, MOSTLY Na_2SO_4	2.8 E2	4.0 E1	NON-COMBUST. LIQUID β-γ
PRECOAT SLUDGE, DIATOMACEOUS EARTH OR CELLULOSIC FIBERS OR POWDERED RESINS	4.2 E1	3.0 E1	COMBUST. β-γ
PURIFIED LIQUID BEAD RESINS	5.7 E0	1.0 E1	COMBUST. β-γ
PRECOAT SLUDGE POWDERED RESIN	5.7 E1	1.0 E1	COMBUST. β-γ
HEPA FILTERS, CHARCOAL, PLASTIC, PAPER, WOOD, METAL, RUBBER	2.8 E2	<5.0 E0	COMBUST. β-γ and NON-COMBUST. SOLID β-γ

SOURCES AND CHARACTERISTICS OF NON-GASEOUS WASTES FROM 1-GWe BWR WITH POWDERED RESIN CONDENSATE CLEANUP

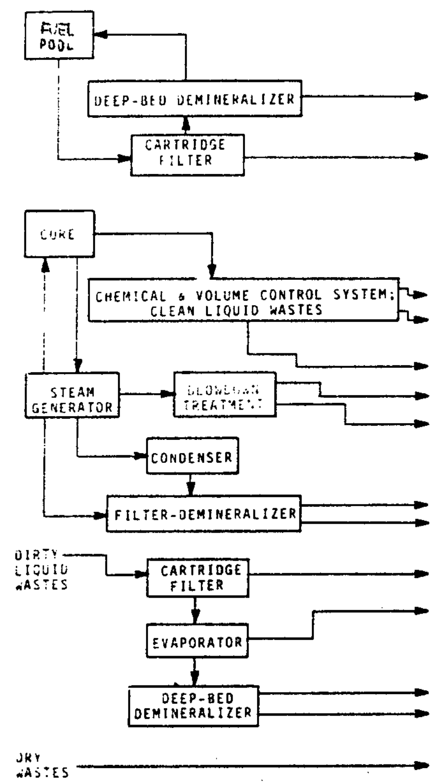


PRIMARY WASTE PER GWe-year

FORM	UNCOMPACTED VOLUME m^3	RADIO-ACTIVITY Ci	TYPE
POWDERED RESIN	2.0 E0	<1.0 E1	COMBUSTIBLE β-γ
POWDERED RESIN	4.8 E0	1.1 E3	COMBUSTIBLE β-γ
POWDERED RESIN	9.4 E1	7.0 E1	COMBUSTIBLE β-γ
CARTRIDGES	2.3 E0	1.0 E0	COMBUSTIBLE β-γ
PURIFIED LIQUID			
BEAD RESINS	2.8 E-1	1.0 E0	COMBUSTIBLE β-γ
SLURRY ∿25% DISSOLVED SOLIDS, MOSTLY Na_2SO_4	1.4 E-1	<1.0 E1	NON-COMBUSTIBLE LIQUID β-γ
PRECOAT SLUDGE, DIATOMACEOUS EARTH OR CELLULOSIC FIBERS OR POWDERED RESIN	1.4 E1	<5.0 E0	COMBUSTIBLE β-γ
PURIFIED LIQUID			
BEAD RESINS	5.7 E0	<1.0 E1	COMBUSTIBLE β-γ
RESIN SLUDGE	4.2 E1	<1.0 E1	COMBUSTIBLE β-γ
HEPA FILTERS, CHARCOAL ABSORBERS CLOTHING, PLASTIC, PAPER, WOOD, METAL, RUBBER	2.8 E2	<5.0 E0	COMBUSTIBLE β-γ and NON-COMBUSTIBLE SOLID β-γ

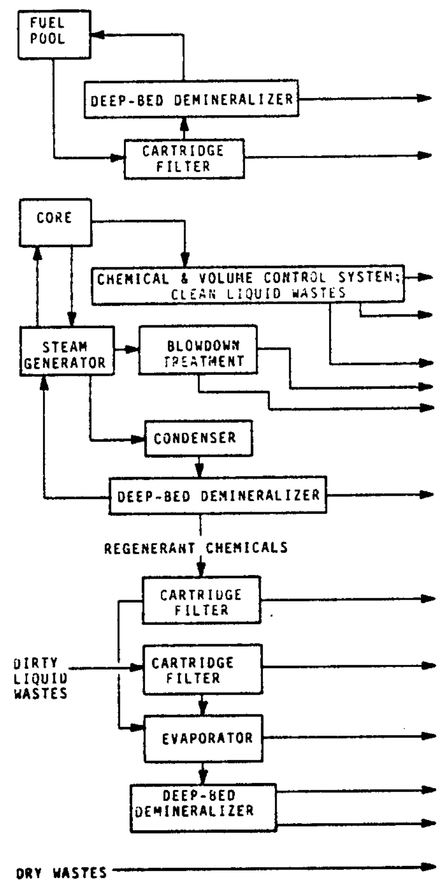
C-3

SOURCES AND CHARACTERISTICS OF NON-GASEOUS WASTES FROM 1-GWe PWR WITH POWDERED RESIN CONDENSATE CLEANUP



	PRIMARY WASTE PER GWe-year		
FORM	UNCOMPACTED VOLUME m^3	RADIO-ACTIVITY Ci	TYPE
BEAD RESINS	1.4 E0	5.0 E0	COMBUSTIBLE β-γ
FILTER CARTRIDGES	1.4 E-1	5.0 E0	COMBUSTIBLE β-γ
BEAD RESINS	8.5 E0	5.5 E3	COMBUSTIBLE β-γ
FILTER CARTRIDGES	2.8 E-1	5.0 E2	COMBUSTIBLE β-γ
EVAPORATOR SLURRY	5.7 E0	5.0 E0	NON-COMBUSTIBLE LIQUID β-γ
BEAD RESINS	8.5 E0	<2.0 E1	COMBUSTIBLE β-γ
FILTER CARTRIDGES	2.8 E0	<1.0 E1	COMBUSTIBLE β-γ
POWDERED RESINS	9.3 E1	<5.0 E0	COMBUSTIBLE β-γ
CARTRIDGES	2.3 E0	<1.0 E-1	COMBUSTIBLE β-γ
CARTRIDGES	2.8 E-1	2.0 E0	COMBUSTIBLE β-γ
SLURRY ~10% DISSOLVED SOLIDS, MOSTLY H_3BO_3	1.7 E1	2.0 E0	NON-COMBUSTIBLE LIQUID β-γ
PURIFIED LIQUID			
BEAD RESINS	1.4 E0	<1.0 E0	COMBUSTIBLE β-γ
HEPA FILTERS, CHARCOAL, CLOTHING, PLASTIC, PAPER, WOOD, METAL, RUBBER	2.3 E2	<5.0 EC	COMBUSTIBLE β-γ and NON-COMBUSTIBLE SOLID β-γ

SOURCES AND CHARACTERISTICS OF NON-GASEOUS WASTES FROM 1-GWe PWR WITH DEEP-BED CONDENSATE CLEANUP



PRIMARY WASTE PER Gwe-year			
FORM	UNCOMPACTED VOLUME m^3	RADIO-ACTIVITY Ci	TYPE
BEAD RESINS	1.4 E0	5.0 E0	COMBUSTIBLE β-γ
FILTER CARTRIDGES	1.4 E-1	5.0 E0	COMBUSTIBLE β-γ
BEAD RESINS	8.5 E0	5.5 E3	COMBUSTIBLE β-γ
FILTER CARTRIDGES	2.8 E-1	5.0 E2	COMBUSTIBLE β-γ
EVAPORATOR SLURRY	5.7 E0	[illegible] E0	NON-COMBUSTIBLE LIQUID β-γ
BEAD RESINS	8.5 E0	<2.0 E1	COMBUSTIBLE β-γ
FILTER CARTRIDGES	2.8 E0	[illegible].0 E1	COMBUSTIBLE β-γ
BEAD RESINS	9.9 E0	<1.0 E0	COMBUSTIBLE β-γ
CARTRIDGES	2.8 E0	1.0 E0	COMBUSTIBLE β-γ
CARTRIDGES	2.8 E-1	2.0 E0	COMBUSTIBLE β-γ
SLURRY ~10% DISSOLVED SOLIDS, MOSTLY H_3BO_3	3.1 E2	<1.0 E1	NON-COMBUSTIBLE LIQUID β-γ
PURIFIED LIQUID			
BEAD RESINS	5.7 E0	<1.0 E0	COMBUSTIBLE β-γ
HEPA FILTERS, CHARCOAL, CLOTHING, PLASTIC, PAPER, WOOD, METAL, RUBBER	2.3 E2	<5.0 E0	COMBUSTIBLE β-γ and NON-COMBUSTIBLE SOLID β-γ

APPENDIX D

GENERAL COMPOSITION OF TYPICAL LWR WASTES*

APPENDIX D

GENERAL COMPOSITION OF TYPICAL LWR WASTES*

1. BEAD RESIN WASTE

Material	Weight Percent, %
Water	50.
Bead Resin (IRN-150)[a]	50.
Temperature	70°F
pH	7

2a. BWR PRECOAT FILTER CAKE (WITH POWDERED RESIN)

Material	Weight Percent in Filter Cake, %
Water	50.
Anion Powdered Resin (PAO)[b]	20.
Cation Powdered Resin (PCH)[b]	20.
Crud[c]	5.
Sodium Chloride	5.
Temperature	70°F
pH	7

2b. BWR PRECOAT FILTER CAKE (WITH DIATOMACEOUS EARTH)

Material	Weight Percent in Filter Cake, %
Water	50.
Diatomaceous Earth	40.
Crud[c]	10.
Temperature	70°F
pH	7

*Appendix A of BNL-NUREG-50571, "Properties of Radioactive Wastes and Waste Containers", Quarterly Progress Report, April-June 1976 P. Colombo and R. M. Nelson, Jr., October 1976.

3a. BWR CHEMICAL REGENERATIVE WASTE OF A FORCED RECIRCULATION EVAPORATOR

Material	Weight Percent in Evaporator Bottoms, %
Water	75.
Sodium Sulfate	22.9
Sodium Chloride	2.0
Crud[c]	0.1
Temperature	170°F
pH	6

3b. PWR CHEMICAL REGENERATIVE WASTE OF A FORCED RECIRCULATION EVAPORATOR

Material	Weight Percent in Evaporator Bottoms, %
Water	73.4
Sodium Sulfate	14.9
Ammonium Sulfate	9.6
Sodium Chloride	2.0
Crud[c]	0.1
Temperature	170°F
pH	2.5 to 4.0

3c. BORIC ACID WASTE OF A FORCED RECIRCULATION EVAPORATOR

Material	Weight Percent in Evaporator Bottoms, %
Water	87.9
Boric Acid	12.0
Crud[c]	0.1
Temperature	170°F
pH	3.5

3d. DECONTAMINATION WASTE OF A FORCED RECIRCULATION EVAPORATOR

Material	Weight Percent in Evaporator Bottoms, %
Water	80.
Nutek NT-700[d]	9.4
EDTA	5.
Citric Acid	5.
Crud[c]	0.2
Hydraulic Oil No. 2	0.2
Lubricating Oil No. 20	0.2
Temperature	170°F
pH	5

4a. BWR CHEMICAL REGENERATIVE WASTE OF A THIN FILM EVAPORATOR

Material	Weight Percent in Evaporator Bottoms, %
Water	50.
Sodium Sulfate	45.8
Sodium Chloride	4.0
Crud[c]	0.2
Temperature	150 to 250°F
pH	6

4b. PWR CHEMICAL REGENERATIVE WASTE OF A THIN FILM EVAPORATOR

Material	Weight Percent in Evaporator Bottoms, %
Water	50.
Sodium Sulfate	29.
Ammonium Sulfate	16.8
Sodium Chloride	4.0
Crud[c]	0.2
Temperature	150 to 250°F
pH	1.8 to 4.0

4c. BORIC ACID WASTE OF A THIN FILM EVAPORATOR

Material	Weight Percent in Evaporator Bottoms, %
Water	50.
Boric Acid	49.8
Crud[c]	0.2
Temperature	150 to 250°F
pH	2.5 to 3.5

4d. DECONTAMINATION WASTE OF A THIN FILM EVAPORATOR

Material	Weight Percent in Evaporator Bottoms, %
Water	50.
Nutek NT-700[d]	20.
EDTA	9.8
Citric Acid	19.
Crud[c]	0.2
Hydraulic Oil No. 2	0.2
Lubricating Oil No. 20	0.2
Temperature	150 to 250°F
pH	5

a Rohm and Haas Co., Philadelphia, PA 19105
b Ecodyne Corp., Union, NJ 07083
c fine air cleaner test dust no. 1543094, AC Spark Plug Division, General Motors Corp., Flint, Michigan 48556
d Nuclear Technology Corp., Amston, CN 06231

APPENDIX E

RADIOACTIVE SHIPMENT RECORDS

APPENDIX E

RADIOACTIVE SHIPMENT RECORDS

FROM ______________________________

______________________________ | CUSTOMER NUMBER |

____

CARRIER: ______________________________

CHEM-NUCLEAR SYSTEMS, INC.
P.O. Box 726, Barnwell, South Carolina 29812
Corporate Office
P.O. Box 1866, Bellevue, Washington 98009

RADIOACTIVE SHIPMENT RECORD FORM

No. 10253

DATE ____________

SURVEY No. ____________

PAGE ____________

OF ____________

CNSI USE ONLY

Date ____________ Survey No. ____________

Date Buried ____________ by ____________

Trench Number ____________

(1) ITEM NUMBER	(2) ISOTOPE	(3) PHYSICAL STATE	(4) GRAMS SNM	(5) POUNDS SOURCE	(6) MILLICURIES RADIOACTIVE	(7) TRANSPORT GROUP	(8) CONTAINER CUBIC FEET	(9) PKG. SPEC.	CASK NUMBER	(11) LOC CODE	(12) CLASSIFICATION	(13) RADIATION LEVEL (mR/HR)		(14) EXTERNAL CONTAMINATION DPM/100cm2	(15) LABEL USED
												SURFACE	AT 3 FEET		
TOTALS															

IMPORTANT This is to certify that the above named articles are properly classified, described, packaged, marked and labeled and are in proper condition for transportation according to the applicable regulations of the Department of Transportation.

Signature ______________________________

Company ______________________________ Date ____________

DESCRIPTION OF ARTICLES
- ☐ Radioactive Material-LSA
- ☐ Radioactive Material-n.o.s.
- ☐ Radioactive Material Special Form
- ☐ Radioactive Material-Large Quantity

DISCLAIMER: Title to all materials which were previously owned by the customer or supplier contained in radioactive waste furnished for burial, shall be deemed to be vested in Chem-Nuclear Systems, Inc. upon delivery to our facility or placed aboard our vehicle. The customer or supplier shall have no right to recovery of any material contained in said waste, nor any credit for their potential value.

Signature ______________________________

Company ______________________________ Date ____________

See Reverse Side For Instructions For Completing This Form

FORM CNS-201

CHEM-NUCLEAR SYSTEMS, INC.

INSTRUCTIONS FOR COMPLETING RADIOACTIVE SHIPMENT RECORD FORM

GENERAL

Customer or shipper must provide information in all numbered column headings except Numbers 11 and 12.

In spaces provided, indicate company name and address, company name of carrier who is transporting the material and the date of the shipment.

An authorized representative of the company must sign and date Certification statement for common carrier shipments and the Disclaimer statement for all shipments.

In the space provided at the bottom of this form check the appropriate box for description of materials.

When transuranic isotopes are involved, the concentration shall not exceed 10 nanocuries per gram and a signed statement to this effect must accompany the Radioactive Shipment Record Form.

Column heading entries are to be made as follows:

(1.) Item or container number - list each container separately.

(2.) Isotope - List each radioisotope contained in each container. The use of the terms MFP and MCP is not permitted. Use as many lines as are required for each container.

(3.) Physical State - indicate state - solid (S), gas (G), scintillation vials (SV).

(4.) Grams SNM - weight in grams of U-235 - cannot exceed 50 grams per 4.0 ft.^{3} or larger container.

(5.) Pounds Source - weight in pounds of U-238 or Th-232.

(6.) Record millicurie quantity of each isotope in each container.

(7.) See Section 173.390 of 49 CFR.

(8.) Record external volume of container (7.5 ft.^{3} for a 55 gal. drum, 4.0 ft.^{3} for a 30 gal. drum.)

(9.) Indicate DOT package specification if applicable, such as 7A.

(10.) Record cask identification number from name plate on cask.

(13.) Record measured radiation levels for each container at the specified distances.

(14.) Contamination levels on containers shall not exceed levels set forth in Section 173.397 (a).

(15.) Packages shall be labeled as required by Sections 172.101, 172.300, 172.400, and 172.403 of 49CFR. No labels are required for LSA containers when transported in a sole or exclusive use vehicle.

APPENDIX F

NECO ENVIRONMENTAL MONITORING ANALYTICAL PROCEDURES

APPENDIX

NECO ENVIRONMENTAL MONITORING ANALYTICAL PROCEDURES

Nuclear Engineering Company, Inc.

Radiological Control Work Procedure

Subject: RADIOANALYSIS PROGRAM — Procedure No. G-002

Technical Concurrence: [signature] — Page 1 of 7

Approval Authorization: [signature]

Rev.	0			
Date	1-24-76			

1.0 INTRODUCTION

This procedure establishes a radioanalysis program which shall be utilized in the analysis of all environmental samples taken at Nuclear Engineering Company burial sites and, as such, provides specific instrument analysis procedure and quality control required in Section 9.5 and 9.6 of the Nuclear Engineering Company Radiological Control & Safety for Burial Sites Manual.

2.0 DISCUSSION

An important factor in any environmental program is an accurate and sensitive radioanalysis program. This procedure contains detailed individual analytical methods and quality assurance for the Beckman 1600 ACC Wide Beta II gas flow proportional counter and the Packard 3320 Liquid Scintillation Spectrometer.

3.0 QUALITY ASSURANCE

Nuclear Engineering Company has an extensive quality assurance program designed to maximize confidence in the analytical procedures.

3.1 Process Quality Control

Process quality control tests the consistency of sample preparation and analysis. Most samples are prepared in batches. Appropriate blanks and reference standards are prepared and analyzed with each batch of samples. In addition, approximately every 50th incoming sample is split and analyzed in duplicate, (the split choice sample is primarily dependent on a sufficient sample quantity).

3.2 Instrument Quality Control

Instrument quality control is designed to ensure that a particular instrument is operating properly. Methods are specific to the instrument and are not sample-dependent. Tests are performed to check and adjust the high voltage, gain and discriminators of the instrument and monitor the background and efficiency.

3.3 Inter-Laboratory Standards Cross-Check Analysis

Inter-laboratory cross-check analysis is carried out by participation in the U. S. Environmental Protection Agency Environmental Radioactivity Laboratory Intercomparison Studies Program. Cross-check samples are analyzed for gross alpha and gross beta in water and air, as well as tritium in water. In addition to the above, some split samples are sent out to other laboratories for analysis and the results are compared with those of NECO.

3.4 Comprehensive Review

Comprehensive review of all data is conducted to assure the integrity of the reported numbers. Analytical results are entered into a prcgramable calculator (Hewlett-Packard-9810) where corrections for efficiency, background, counting time, and volume of sample are made and final results are calculated. Results noted as unusual are carefully reviewed and, as appropriate, recommendations made to reanalyze the sample, to take additional samples or to take other action needed to explain the anomalous results. Results of an unusual nature are communicated to the originator in a timely manner.

4.0 ANALYTICAL PROCEDURES

Measurable amounts of alpha and beta emitting radionuclides are found in most environmental waters, soils and vegetations. They include naturally occurring radionuclides such as uranium, radium, thorium and potassium 40 as well as radionuclides introduced by man. Since analytical techniques employed in measurement of the more radiotoxic radionuclides (Ra-226 and Sr-90) are complex and time consuming, gross alpha and gross beta analysis are employed as a simple screening technique which will indicate or negate the need for specific analysis.

4.1 Gross Alpha and Gross Beta Radioactivities in Environmental Waters

4.1.1 Summary - Environmental water samples are normally divided into two portions for analysis. A filter (0.45 um) is used to separate the suspended particles from those dissolved in the water. This allows for analysis of each sample individually making for a more comprehensive review of the results.

4.1.2 Apparatus - Filtering appartus - 47 mm (Gelman)
47 mm diameter 0.45 micrometer membrane filter
(cellulose triacetate type)
Filter flash - 500 nl
Tygon tubing
Vacuum pump
Graduated cylinders, 100.500 ml.
Stainless steel planchets (2"x1/4")
Drying oven
Alpha and beta counting system
(Beckman Wide Beta II)
Beakers - 50- m.
Crucible and cover

4.1.3 Reagents -
Acetone
Acetone - Lucite fixing agent
Nitric acid 2IN and .4N

4.1.4 Sample Size and Counting Efficiency - Sample residue self-absorption must be considered for both alpha and beta radioactivities when choosing the sample aliquot size. Increasing sample size and, therefore, increasing sample residue can in some instance be reducing the overall efficiency of the method. A sample size should be chosen so as to deliver a residue of approximately 5 mg/cm^2 of planchet area.

4.1.5 Method -
1. Select the volume of sample to be used (see 4.1.4).
2. Obtain a pH and record this in the appropriate location on the data sheet.
3. Filter the sample using a 0.45 micrometer filter. (Prefilter with a coarse paper may be necessary on sample containing large quantities of suspended material.)
4. Acidify the filtrate with 2 ml. of .1N nitric acid and evaporate to near dryness.
5. Remove the filter and ash in a muffle furnace at 450°c.
6. Transfer 0.1 g of the sample to a tared planchet.
7. Add 1 ml of acetone-lucite fixing agent.
8. Weigh the planchet and record its weight.
9. When the filtrate is nearly evaporated (5ml remaining), place in a tared planchet using a rubber policeman and .4N nitric acid.
10. Evaporate to dryness under a heat lamp.
11. Weigh and record the planchet weight.

4.1.6 Counting -
1. Each planchet is counted for 50 minutes for alpha and beta activity.
2. A blank planchet is run every tenth sample, or at the end of each sample set.

4.1.7 Calculations - The gross counts from the counting instrument are corrected for counting efficiency (including mount weight), background and volume size. Suspended activities are reported in units of pCi/l and pCi/gm. Dissolved portions are reported in pCi/l. A two sigma error is calculated and reported. Data reduction is accomplished by programable calculator. Samples containing less than minimum detectable activities are reported as less than MDA.

4.2 Gross Alpha and Gross Beta Radioactivities in Soil

4.2.1 Summary - Organic matter is removed from the sample prior to preparation. The samples are ashed, sieved and mounted on planchets for counting.

4.2.2 Apparatus -
Crucible and cover
Muffle furnace
Mortar and pestle
Stainless steel planchet (2"x1/4")
Screen sieve (200 mesh)
Counting instrument (Beckman Wide Beta II)

4.2.3 Reagents -
Acetone
Acetone-lucite fixing agent

4.2.4 Sample size and counting efficiency - Sample residue self absorption must be considered for both alpha and beta radioactivities when choosing a sample (mount weight) size. A planchet mount weight of 5 mgl cm^2 should be used.

4.2.5 Method -
1. Thoroughly mix the soil to ensure a representative sample.
2. Ash approximately 50 gms of sample in a porcelain crucible for 30 minutes at 450^{o}c.
3. Reduce the dried sample to a fine powder with motor* and pestle.

* [sic]

CN1

4. Weigh and label a prepared planchet and record the necessary information on the data sheet.
5. Add 1 ml of acetone-lucite fixing agent and 1 ml. of acetone to the planchet.
6. Transfer approximately 0.1 gram of the dried sample to the planchet using a 200 mesh screen.
7. Weigh the planchet and record the weight.

4.2.6 Counting -
1. Soil samples are counted for 50 minutes for alpha and beta activity.
2. A blank planchet is run every tenth sample, or at the end of each sample set.

4.2.7 Calculations - The gross counts from the counting instrument are corrected for counting efficiency (including mount weight), background and sample weight. The activity is reported in units of pCi/gm-dried weight. Data reduction is accomplished by a programable calculator. A two signia* error is calculated and reported. Samples containing less than minimum detectable activities are reported as less than the MDA.

4.3 Gross Alpha and Gross Beta Radioactivity in Vegetation

4.3.1 Summary - The sample which has been selected from grasses and vegetables near the site is ashed, sieved and mounted on planchets for counting.

4.3.2 Apparatus -
Food blender
Crucible and cover
Muffle furnace
Stainless steel planchet (2"x1/4")
Screen sieve (200 mesh)
Counting instrument (Beckman Wide Beta II)

4.3.3 Reagents -
Acetone
Acetone-lucite fixing agent

4.3.4 Sample Size and Counting Efficiency - Sample residue self absorption must be considered for both alpha and beta radioactivities when choosing a sample size (mount weight). A planchet mount weight of 5 mg/cm^2 should be used.

* [sic]

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4.3.5 Method -

1. Dry a minimum of 10 grams of vegetation in a braker on a hot plate.
2. Reduce the dried sample to a coarse powder in a food blender.
3. Transfer 5 grams of sample into a tared, labelled crucible.
4. Weigh the dried sample and the crucible and record this weight on a data sheet.
5. Ash the sample at 450°c for 30 minutes.
6. Weigh the crucible and record this weight.
7. Add 1 ml of acetone and 1 ml of fixing agents to a tared planchet.
8. Transfer 100 mg. of ash to the planchet using the 200 mesh screen when necessary.
9. Weigh the planchet and store for later counting.

4.3.6 Calculations - The gross counts are corrected for efficiency (including mount weight), background, and sample weight. The activity is reported in units of pCi/gm for both dried and ashed weights. Data reduction is accomplished by a programable calculator. A two-sigma error is calculated and reported. Samples having less than minimum detectable activities are reported as less than the MDA.

4.4 Tritium Radioactivity in Environmental Water

4.4.1 Summary - An aliquot of sample is distilled to eliminate dissolved gases and non-volatile molter* and counted by liquid scintillation counting.

4.4.2 Apparatus -
Liquid scintillation spectrometer
Distillation apparatus
Vails* (24 ml low K-40 glass)
Pipette
Water bath
Automatic shaker

4.4.3 Reagents -
Scintillator solution (Insta-gel R)
Calibrated tritium standard
Aged water

* [sic]

4.4.4 Method -

1. Transfer approximately 50 ml. of sample to the distillation apparatus. Collect at least 10 ml. of sample.
2. Using an accurate pipette transfer 8 m. of sample to 24 ml. vial.
3. Add 10 ml. of scintillator solution to the vial.
4. Place the vial in a 38°c water bath (agitating intermittantly) until the solution is clear and fluid.
5. Shake the vial in an automatic shaker for one minute.
6. Wipe the vial with a clean lint-free towel (Kim-wipe) to remove fingerprints.
7. Place the vial in the counter sample changer belt and allow to dark adapt for four hours prior to counting.

4.4.5 Counting -

1. Samples are counted for 100 minutes each.
2. An aged water blank is counted each tenth sample, or at the end of each sample set.

4.4.6 Calculations - Significant reduction in the absolute counting efficiency may result from quenching caused by impurities in the sample which are introduced into the scintillator solution and which will inhibit the transfer of energy or by color in the sample which may absorb the emmitted light. Corrections must be made for quenching or quenching materials removed from the sample (distillation). Correction for quenching can be accomplished either by the use of an internal standard or an external standard. Both methods are used at the NECO laboratory with external standards method acting as a screening procedure to see if internal standards methods are necessary.

The gross counts from the counting system are corrected for efficiency (including quenching), background and sample volume. The results are reported in units of microcuries per milliliter. A two sigma error is also report*. Sample having less than minimum detectable activities are reported as less than the MDA.

* [sic]

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APPENDIX G

ENVIRONMENTAL MONITORING - BARNWELL FACILITY PROGRAM

APPENDIX G

ENVIRONMENTAL MONITORING - BARNWELL FACILITY PROGRAM

SUBJECT: BARNWELL FACILITY PROGRAM

I. ENVIRONMENTAL MONITORING PROGRAM

The main purpose of an environmental monitoring program at a low level radioactive waste burial facility is to determine if there is any movement of radioisotopes from the burial trenches to the environment. Any movement of material from the trenches would occur when such material is carried by an underground water course. The detection of any such movement is made through an extensive sampling program in, and adjacent to, the trenches.

Initial ground-water investigations at the Chem-Nuclear Systems, Inc.'s site indicate that any radioisotopes which may, in fact, reach the aquifers will be carried to the Southwest and would be diluted to well below applicable MPC's before they became available in usable aquifers. Numerous wells have been drilled throughout the burial facility for monitoring purposes. These wells, for the most part, are drilled into the miocene which contains the first aquifer and which would be the first available media for the transportation of radioisotopes.

Following is a description of the various wells:

A. Sanitary wells - two such wells have been drilled into the eocine and are used to supply water for drinking, et cetera.

B. Ring Wells - a series of wells have been, and will continue to be, drilled into the miocene as recommended by our Geologist. These wells are observed on a routine schedule for water level and are sampled on on an established schedule. Radioanalyses are conducted on these samples.

C. Trench wells - one each such well is located within 20 feet of the low end of each burial trench and is drilled into the miocene. These wells are observed on a routine schedule for water level and are sampled on an established schedule. Radioanalyses are conducted on these samples.

D. Sump wells - four each vertical pipes are placed at equidistance from each other and into the french drain sump which is constructed on the centerline of each burial trench. These sump wells are observed on a routine schedule for the presence of liquid. If liquid is observed in any of these wells, samples are obtained and radioanalyses are performed. In addition, the Director, Division of Radiological Health will be notified immediately if liquid is

observed in any of the sump wells.

II. Following is the established schedule for observation, sampling and radioanalysis:

Activity	Sanitary Wells	Ring Wells	Trench Wells	Sump Wells
Liquid level observation	N/A	Mar. & Sep.	Monthly	Monthly
Gross Beta, Alpha Analysis	Semi-annual	Semi-annual	Quarterly	As required
Tritium Analysis	Semi-annual	Semi-annual	Quarterly	As required
Geli-Isotopic Analysis	As required*	As required*	As required*	" " *

*A Ge-Li or isotopic analysis will be performed on all samples which indicate significant gross beta-gamma-alpha activity.

III. Soil and Vegetation Sampling

Base line soil and vegetation samples are obtained at six (6) pre-selected locations on Chem-Nuclear Systems, Inc.'s property on an annual basis. These samples are analyzed for gross beta-gamma-alpha activity. If the results of these analyses are significant, a Ge-Li isotopic analysis will be performed.

As an additional measure to detect any spread of radioactive material which could be attributed to CNSI operations, weekly soil samples are taken, one each from completed trenches, several in the vicinity of an operating trench and several at random locations throughout the site. These samples are surveyed with a shielded pancake type GM detector having a window density of 1 - 2 mg/cm.^{2} If surveys indicate significant levels of radioactivity, additional samples will be obtained. If contamination in ground areas is confirmed, decontamination will be effected by excavating soils and burial. The results of these surveys and of any required corrective action will be documented.

IV. Air Sampling

One low volume constant flow air sampler is operated on a continuous basis at a location which is normally downwind from the burial trenches, a two(2) inch membrane particulate filter having a pore size of 1.2 micrometers is currently used. The filter paper is checked daily with an end window GM detector. The filter is changed on a weekly basis and quantitatively counted for beta-gamma and alpha emitters.

SUBJECT: BARNWELL FACILITY PROGRAM

I. ENVIRONMENTAL MONITORING PROGRAM

The main purpose of an environmental monitoring program at a low level radioactive waste burial facility is to determine if there is any movement of radioisotopes from the burial trenches to the environment. Any movement of material from the trenches would occur when such material is carried by an underground water course. The detection of any such movement is made through an extensive sampling program in, and adjacent to, the trenches.

Initial ground-water investigations at the Chem-Nuclear Systems, Inc.'s site indicate that any radioisotopes which may, in fact, reach the aquifers will be carried to the Southwest and would be diluted to well below applicable MPC's before they became available in usable aquifers. Numerous wells have been drilled throughout the burial facility for monitoring purposes. These wells, for the most part, are drilled into the miocene which contains the first aquifer and which would be the first available media for the transportation of radioisotopes.

Following is a description of the various wells:

A. Sanitary wells - two such wells have been drilled into the eocine and are used to supply water for drinking, et cetera.

B. Ring Wells - a series of wells have been, and will continue to be, drilled into the miocene as recommended by our Geologist. These wells are observed on a routine schedule for water level and are sampled on on an established schedule. Radioanalyses are conducted on these samples.

C. Trench wells - one each such well is located within 20 feet of the low end of each burial trench and is drilled into the miocene. These wells are observed on a routine schedule for water level and are sampled on an established schedule. Radioanalyses are conducted on these samples.

D. Sump wells - four each vertical pipes are placed at equidistance from each other and into the french drain sump which is constructed on the centerline of each burial trench. These sump wells are observed on a routine schedule for the presence of liquid. If liquid is observed in any of these wells, samples are obtained and radioanalyses are performed. In addition, the Director, Division of Radiological Health will be notified immediately if liquid is

APPENDIX H

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APPENDIX I

GLOSSARY

ACGIH	American Conference of Governmental Industrial Hygienists
ACIDOSIS	High blood acidity
ACUTE	Sharp, poignant; having a short and relatively severe course; single administration
ALVEOLAR	Pertaining to the small saclike dilatations of the lung, through the walls of which gas exchange takes place between the inspired air and pulmonary capillary blood
ANEMIA	A reduction below normal in the number of red blood cells, in the quantity of hemoglobin, or in the volume of packed red cells per 100 ml of blood which occurs when the equilibrium between blood loss and blood production is disturbed
ANESTHESIA	Loss of feeling or sensation, especially the sensation of pain
ANTICOAGULANT	Serving to prevent the coagulation of blood
ANTINEOPLASTIC	Inhibiting or preventing the development of neoplasms
ATP	Adenosine triphosphate; a compound occurring in all cells, where it represents energy storage
ATPase	Adenosinetriphosphatase; an enzyme which catalyzes the splitting of ATP, with liberation of inorganic phosphate
BENIGN	Not malignant, not recurrent
BILIRUBIN	A bile pigment; it is a breadkdown product of heme mainly from the degradation of red blood cell hemoglobin
CAPILLARY	Any one of the minute blood vessels that connect the anterioles and venules, forming a network in nearly all parts of the body. Their walls act as semi-permeable membranes for the interchange of various substances, including fluids, between the blood and tissue fluid
CARCINOGENIC	Producing carcinoma
CARCINOGENICITY	The potential, ability, or tendency to produce carcinoma
CARCINOMA	A malignant new growth made up of epithelial cells tending to infiltrate the surrounding tissues and to metastasize

CATHARSIS	A cleansing or purgation
Ci	Curie, a unit of radioactivity
CNS	Central Nervous System
COFACTOR	An element or principle, as a coenzyme, with which another must unite in order to function
COMA	A state of unconsciousness from which the patient cannot be aroused, even by powerful stimulation
CONJUNCTIVA	The delicate membrane that lines the eyelids and covers the exposed surface of the sclera (the white outer coat of the eyeball)
CONTRACTILITY	The capacity for contracting (becoming short) in response to a suitable stimulus
CORNEAL	Pertaining to the transparent structure forming the anterior part of the fibrous tunic of the eye
CUEX	Cumulative Exposure Index
DERMATITIS	Inflammation of the skin; a general term
ECG	Electrocardiogram
EDEMA	Presence of abnormally large amounts of fluid in the intercellular tissue spaces of the body
EDEMATOUS	Pertaining to or affected by edema
ELECTROENCEPHALOGRAM	A recording of the potentials on the skull generated by currents emanating spontaneously srom nerve cells in the brain.
EPC	Estimated permissible concentration, for a chemical substance
ERYTHEMA	Redness of the skin, produced by congestion of the capillaries
ERYTHEMATOUS	Characterized by erythema
GASTROENTERIC	Pertaining to the stomach and intestines
GASTROENTERITIS	Inflammation of the stomach and intestines
GASTROINTESTINAL	Pertaining to the stomach and intestines
GONADAL	Pertaining to a gamete-producing gland: an ovary or testis

HEMATOPOIETIC	Pertaining to or affecting the formation of blood cells
HEMOCHRONMATOSIS	A disorder of iron metabolism characterized by excess deposition of iron in the tissues, especially in the liver and pancreas, and by bronze pigmentation of the skin, cirrhosis, diabetes mellitus, and associated bone and joint changes
HEMOGLOBINEMIA	The presence of excessive hemoglobin in the plasma of the blood
HEMOGLOBURNIA	The presence of free hemoglobin in the urine
HEMOLYSIS	The liberation of hemoglobin; the separation of hemoglobin from the red blood cells and its appearance in the plasma
HEMOLYTIC	Pertaining to, characterized by, or producing hemolysis
HEMOSIDEROSIS	A focal or general increase in tissue iron stores without associated tissue damage
HEPATIC	Pertaining to the liver.
HEPATORENAL	Pertaining to the liver and kidneys
HISTOPATHOLOGICAL	Abnormal tissue changes identified with a microscope
HYPERPNEA	Abnormal increase in the depth and rate of the respiratory movements
HYPOCALCEMIA	Reduction of the blood calcium below normal
IAEA	International Atomic Energy Commission
ICRP	International Commission for Radiation Protection
INTRAPERITONEAL	Within the peritoneal cavity
INTRAVENOUS	Within a vein or veins
IN VITRO	Within a glass; observable in a test-tube; in an artificial environment
LACRIMATION	The secretion and discharge of tears
LD_{50}	Predicted lethal dose for 50% of the organisms in a test population
LD_{LO}	Lowest lethal dose observed
LIPIPHILICITY	Affinity for fat, lipids

MATE	Minimum Acute Toxicity Effluents
MEG	Multimedia Environmental Goals
METABOLIC ACIDOSIS	A disturbance in which the acid-base status of the body shifts toward the acid side because of loss of base or retention of noncarbonic, or fixed (nonvolatile), acids
METABOLIZE	To subject a substance to metabolism - the complex of physical and chemical processes by which living organized substance is produced and maintained and by which energy is made available for uses of the organism
MITOCHONDRIAL	Of or pertaining to mitochondria--small organelles found in the cytoplasm of cells and the principal sites of energy generation resulting from the oxidation of foodstuffs
MIXED FUNCTION OXIDASES	Enzyme which introduce only one oxygen atom into the substrate
MPBB	Mpzimum Permissible Body Burden
MPC	Maximum Permissible Concentration, for a radioactive substance
MPC_A	MPC in air
MPC_W	MPC in water
MUTAGENIC	Inducing genetic mutation--a permanent, transmissible change in genetic material
MYOCARDIUM	The middle and thickest layer of the heart wall, composed of cardiac muscle
NARCOSIS	A reversible condition characterized by stupor or insensibility
NARCOTIC	Pertaining to or producing narcosis; an agent that produces insensibility or stupor
NECROSIS	Death of tissues, usually as individual cells, groups of cells, or in small, localized areas
NEOPLASM	Any new and abnormal growth, specifically a new growth of tissue in which the growth is uncontrolled and progressive
NEPHRITE	Inflammation of the kidney
NEUROLOGICAL	Pertaining to the nervous system

NEUROMUSCLAR	Pertaining to muscles and nerves
OSHA	Occupational Safety and Health Administration
OSTEOSCLEROSIS	The hardening or abnormal density of bone
OXIDASE	Any of a group of enzymes which catalyze oxidations; especially one able to react directly with molecular oxygen
PERIPHERAL RESISTANCE	The resistance to the passage of blood through the small blood vessels, especially the arterioles
PHI	Potential Hazard Index
PLASMA	The fluid portion of the blood in which the blood cells are suspended
PNEUMOCONIOSIS	A condition characterized by permanent deposition of substantial amounts of particulate matter in the lungs, and by the tissue reaction to its presence
REC	REM-Equivalent-Chemical
RENAL	Pertaining to the kidney
RHI	Radiotoxic Hazard Index
RHM	Relative Hazard Measure
SILICOSIS	Pneumoconiosis due to the inhalation of the dust of stone, sand, or flint containing silicon dioxide, with formation of generalized fibrotic nodular changes in both lungs
SOMNOLENCE	Sleepiness; unnatural drowsiness
SUBLETHAL	Not quite fatal; insufficient to cause death
TERATOGENIC	Causing the production of physical defects in the developing embryo
THROMBOPHLEBITIS	Inflamation of a vein associated with thrombus formation (on aggregation of blood factors, primarily platelets and fibrin with entrapment of cellular elements, frequently causing vascular obstruction)
TLm 96	Tolerance Limit median: the concentration of a substance in water which will cause the death of 50 percent of an experimental aquatic animal population under controlled conditions and time of exposure (1 most of 96 hours)
TLV	Threshold Limit Value

VENTILATION	The process of exchange of air between the lungs and the ambient air
VENTRICULAR	Abnormal rhythm of the ventricular muscle of the heart, VENTRICULAR characterized by rapid repetitive excitation of myocardial fibers without coordinated contraction of the ventricle
VERTIGO	An illusion of movement; a sensation as if the external world were revolving around the patient or as if the patient were revolving in space.

APPENDIX J

§ 20.207 Storage and control of licensed materials in unrestricted areas.

(a) Licensed materials stored in an unrestricted area shall be secured from unauthorized removal from the place of storage.

(b) Licensed materials in an unrestricted area and not in storage shall be tended under the constant surveillance and immediate control of the licensee.

WASTE DISPOSAL

§ 20.301 General requirement.

No licensee shall dispose of licensed material except:

(a) By transfer to an authorized recipient as provided in the regulations in Part 30, 40, or 70 of this chapter, whichever may be applicable; or

(b) As authorized pursuant to § 20.302; or

(c) As provided in § 20.303 or § 20.304, applicable respectively to the disposal of licensed material by release into sanitary sewerage systems or burial in soil, or in § 20.106 (Radioactivity in Effluents to Unrestricted Areas)

§ 20.302 Method for obtaining approval of proposed disposal procedures.

* (a) Any licensee or applicant for a license may apply to the Commission for approval of proposed procedures to dispose of licensed material in a manner not otherwise authorized in the regulations in this chapter. Each application should include a description of the licensed material and any other radioactive material involved, including the quantities and kinds of such material and the levels of radioactivity involved, and the proposed manner and conditions of disposal. The application should also include an analysis and evaluation of pertinent information as to the nature of the environment, including topographical, geological, meteorological, and hydrological characteristics; usage of ground and surface waters in the general area; the nature and location of other potentially affected facilities; and procedures to be observed to minimize the risk of unexpected or hazardous exposures.

* (b) The Commission will not approve any application for a license to receive licensed material from other persons for disposal on land not owned by the Federal government or by a State government.

(c) The Commission will not approve any application for a license for disposal of licensed material at sea unless the applicant shows that sea disposal offers less harm to man or the environment than other practical alternative methods of disposal.

§ 20.303 Disposal by release into sanitary sewerage systems.

No licensee shall discharge licensed material into a sanitary sewerage system unless:

(a) It is readily soluble or dispersible in water; and

(b) The quantity of any licensed or other radioactive material released into the system by the licensee in any one day does not exceed the larger of subparagraphs (1) or (2) of this paragraph:

(1) The quantity which, if diluted by the average daily quantity of sewage released into the sewer by the licensee, will result in an average concentration equal to the limits specified in Appendix B, Table I, Column 2 of this part; or

(2) Ten times the quantity of such material specified in Appendix C of this part; and

(c) The quantity of any licensed or other radioactive material released in any one month, if diluted by the average monthly quantity of water released by the licensee, will not result in an average concentration exceeding the limits specified in Appendix B, Table I, Column 2 of this part; and

(d) The gross quantity of licensed and other radioactive material released into the sewerage system by the licensee does not exceed one curie per year.

Excreta from individuals undergoing medical diagnosis or therapy with radioactive material shall be exempt from any limitations contained in this section.

§ 20.304 Disposal by burial in soil.

No licensee shall dispose of licensed material by burial in soil unless:

(a) The total quantity of licensed and other radioactive materials buried at any one location and time does not exceed, at the time of burial, 1,000 times the amount specified in Appendix C of this part; and

(b) Burial is at a minimum depth of four feet; and

(c) Successive burials are separated by distances of at least six feet and not more than 12 burials are made in any year.

§ 20.305 Treatment or disposal by incineration.

No licensee shall treat or dispose of licensed material by incineration except as specifically approved by the Commission pursuant to §§ 20.106(b) and 20.302.

RECORDS, REPORTS, AND NOTIFICATION

§ 20.401 Records of surveys, radiation monitoring, and disposal.

(a) Each licensee shall maintain records showing the radiation exposures of all individuals for whom personnel monitoring is required under § 20.202 of the regulations in this part. Such records shall be kept on Form NRC-5, in accordance with the instructions contained in that form or on clear and legible records containing all the information required by Form NRC-5. The doses entered on the forms or records shall be for periods of time not exceeding one calendar quarter.

(b) Each licensee shall maintain records in the same units used in this part, showing the results of surveys required by § 20.201(b), monitoring required by §§ 20.205(b) and 20.205(c), and disposals made under §§ 20.302, 20.303, and 20.304.

(c)(1) Records of individual exposure to radiation and to radioactive material which must be maintained pursuant to the provisions of paragraph (a) of this section and records of bioassays, including results of whole body counting examinations, made pursuant to § 20.108, shall be preserved until the Commission authorizes disposition.

(2) Records of the results of surveys and monitoring which must be maintained pursuant to paragraph (b) of this section shall be preserved for two years after completion of the survey except that the following records shall be maintained until the Commission authorizes their disposition: (i) records of the results of surveys to determine compliance with § 20.103(a); (ii) in the absence of personnel monitoring data, records of the results of surveys to determine external radiation dose; and (iii) records of the results of surveys used to evaluate the release of radioactive effluents to the environment.

(3) Records of disposal of licensed material made pursuant to §§ 20.302, 20.303, or 20.304 shall be maintained until the Commission authorizes their disposition.

(4) Records which must be maintained pursuant to this part may be the original or a reproduced copy or microform if such reproduced copy or microform is duly authenticated by authorized personnel and the microform is capable of producing a clear and legible copy after storage for the period specified by Commission regulations.

(5) If there is a conflict between the Commission's regulations in this part, license condition, or technical specification, or other written Commission approval or authorization pertaining to the retention period for the same type of record, the retention period specified in the regulations in this part for such records shall apply unless the Commission pursuant to § 20.501, has granted a specific exemption from the record retention requirements specified in the regulations in this part.

§ 20.402 Reports of theft or loss of licensed material.

(a) Each licensee shall report by telephone to the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix D, immediately after its occurrence becomes known to the licensee, any loss or theft of licensed material in such quantities and under such circumstances that it appears to the licensee that a substantial hazard may result to persons in unrestricted areas.

(b) Each licensee who is required to make a report pursuant to paragraph (a) of this section shall, within thirty (30) days after he learns of the loss or theft, make a report in writing to the appropriate NRC Regional Office listed in Appendix D with copies to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, setting forth the following information:

*Redesignated 36 FR 23138.

Amended 42 FR 43965.

APPENDIX C

Material	Microcuries
Americium-241	.01
Antimony-122	100
Antimony-124	10
Antimony-125	10
Arsenic-73	100
Arsenic-74	10
Arsenic-76	10
Arsenic-77	100
Barium-131	10
Barium-133	10
Barium-140	10
Bismuth-210	1
Bromine-82	10
Cadmium-109	10
Cadmium-115m	10
Cadmium-115	100
Calcium-45	10
Calcium-47	10
Carbon-14	100
Cerium-141	100
Cerium-143	100
Cerium-144	1
Cesium-131	1,000
Cesium-134m	100
Cesium-134	1
Cesium-135	10
Cesium-136	10
Cesium-137	10
Chlorine-36	10
Chlorine-38	10
Chromium-51	1,000
Cobalt-58m	10
Cobalt-58	10
Cobalt-60	1
Copper-64	100
Dysprosium-165	10
Dysprosium-166	100
Erbium-169	100
Erbium-171	100
Europium-152 9.2 h	100
Europium-152 13 yr	1
Europium-154	1
Europium-155	10
Fluorine-18	1,000
Gadolinium-153	10
Gadolinium-159	100
Gallium-72	10
Germanium-71	100
Gold-198	100
Gold-199	100
Hafnium-181	10
Holmium-166	100
Hydrogen-3	1,000
Indium-113m	100
Indium-114m	10
Indium-115m	100
Indium-115	10
Iodine-125	1
Iodine-126	1
Iodine-129	0.1
Iodine-131	1
Iodine-132	10
Iodine-133	1
Iodine-134	10
Iodine-135	10
Iridium-192	10
Iridium-194	100
Iron-55	100
Iron-59	10
Krypton-85	100
Krypton-87	10
Lanthanum-140	10
Lutetium-177	100
Manganese-52	10
Manganese-54	10
Manganese-56	10
Mercury-197m	100
Mercury-197	100
Mercury-203	10
Molybdenum-99	100
Neodymium-147	100
Neodymium-149	100
Nickel-59	100
Nickel-63	10
Nickel-65	100
Niobium-93m	10
Niobium-95	10
Niobium-97	10
Osmium-185	10
Osmium-191m*	100
Osmium-191	100
Osmium-193	100
Palladium-103	100
Palladium-109	100
Phosphorus-32	10
Platinum-191	100
Platinum-193m	100
Platinum-193	100
Platinum-197m	100
Platinum-197	100
Plutonium-239	.01
Polonium-210	0.1
Potassium-42	10
Praseodymium-142	100
Praseodymium-143	100
Promethium-147	10
Promethium-149	10
Radium-226	.01
Rhenium-186	100
Rhenium-188	100
Rhodium-103m	100
Rhodium-105	100
Rubidium-86	10
Rubidium-87	10
Ruthenium-97	100
Ruthenium-103	10
Ruthenium-105	10
Ruthenium-106	1
Samarium-151	10
Samarium-153	100
Scandium-46	10
Scandium-47	100
Scandium-48	10
Selenium-75	10
Silicon-31	100
Silver-105	10
Silver-110m	1
Silver-111	100
Sodium-24	10
Strontium-85	10
Strontium-89	1
Strontium-90	0.1
Strontium-91	10
Strontium-92	10
Sulphur-35	100
Tantalum-182	10
Technetium-96	10
Technetium-97m	100
Technetium-97	100
Technetium-99m	100
Technetium-99	10
Tellurium-125m	10
Tellurium-127m	10
Tellurium-127	100
Tellurium-129m	10
Tellurium-129	100
Tellurium-131m	10
Tellurium-132	10
Terbium-160	10
Thallium-200	100
Thallium-201	100
Thallium-202	100
Thallium-204	10
**Thorium (natural)[1]	100
Thulium-170	10
Thulium-171	10
Tin-113	10
Tin-125	10
Tungsten-181	10
Tungsten-185	10
Tungsten-187	100
**Uranium (natural)[2]	100
Uranium-233	.01
Uranium-234—Uranium-235	.01
Vanadium-48	10
Xenon-131m	1,000
Xenon-133	100
Xenon-135	100
Ytterbium-175	100
Yttrium-90	10
Yttrium-91	10
Yttrium-92	100
Yttrium-93	100
Zinc-65	10
Zinc-69m	100
Zinc-69	1,000
Zirconium-93	10
Zirconium-95	10
Zirconium-97	10
Any alpha emitting radionuclide not listed above or mixtures of alpha emitters of unknown composition	.01
Any radionuclide other than alpha emitting radionuclides, not listed above or mixtures of beta emitters of unknown composition	.1

NOTE: For purposes of §§ 20.203 and 20.304, where there is involved a combination of isotopes in known amounts the limit for the combination should be derived as follows: Determine, for each isotope in the combination, the ratio between the quantity present in the combination and the limit otherwise established for the specific isotope when not in combination. The sum of such ratios for all the isotopes in the combination may not exceed "1" (i.e., "unity"). Example: For purposes of § 20.304, if a particular batch contains 20,000 µCi† of Au^{198} and 50,000 µCi† of C^{14}, it may also include not more than 300 µCi† of I^{131}. This limit was determined as follows:

$$\frac{20{,}000\ \mu Ci\ Au^{198}}{100{,}000\ \mu Ci} + \frac{50{,}000\ \mu Ci\ C^{14}}{100{,}000\ \mu Ci} + \frac{300\ \mu Ci\ I^{131}}{1{,}000\ \mu Ci} = 1$$

The denominator in each of the above ratios was obtained by multiplying the figure in the table by 1,000 as provided in § 20.304.

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[1] Based on alpha disintegration rate of Th-232, Th-230 and their daughter products.

[2] Based on alpha disintegration rate of U-238, U-234, and U-235.

* Amended 36 FR 16898.

** Amended 39 FR 23990.

† Amended 38 FR 29314.

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16. ABSTRACT *(200 words or less)*

The chemical composition of fuel-cycle wastes is reasonably well known. By comparison, there is little information on the chemical composition of non-fuel cycle wastes. Such non-fuel cycle wastes come from a variety of sources--industrial, chemical, and medical. Because of the paucity of information, it is difficult to define the chemical characteristics and to evaluate potential hazards of non-fuel cycle wastes as a result of chemical toxicity.

This report provides an assessment of the chemical toxicity of low-level radioactive wastes based on literature reviews, preparation of bibliographies and monographs, and application of a variety of methodologies either being currently applied or being proposed for relative hazard assessments. The report relies primarily on data from the Maxey Flats, Kentucky waste disposal site. While there are differences between humid and dry sites, the findings are believed to be generally applicable to evaluating th- chemical toxicity of wastes at all low-level radioactive waste burial sites.

17. KEY WORDS AND DOCUMENT ANALYSIS 17a. DESCRIPTORS

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